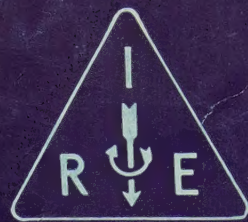


IRE Transactions



ON VEHICULAR COMMUNICATIONS

PGVC-12

PERIODICAL
UNIVERSITY OF HAWAII
LIBRARY

APRIL, 1959

*Ninth National Conference
of the
Professional Group on Vehicular Communications
of the
Institute of Radio Engineers*

Hotel Sherman, Chicago, Illinois
December 4 and 5, 1958

TK7882
M6113

PUBLISHED BY THE

PROFESSIONAL GROUP ON VEHICULAR COMMUNICATIONS

IRE PROFESSIONAL GROUP ON VEHICULAR COMMUNICATIONS

The Professional Group on Vehicular Communications is an organization, within the framework of the IRE, of members with principal professional interest in Vehicular Communications. All members of the IRE are eligible for membership in the Group and will receive all Group publications upon payment of prescribed fees.

Annual Fee: \$2.00

Administrative Committee

ANGUS A. MACDONALD, *Chairman*

JOSEPH E. KELLER, *Vice-Chairman*

S. C. BARTLETT, *Secretary & Treasurer*

A. B. BUCHANAN

G. E. DODRILL

R. P. GIFFORD

C. M. HEIDEN

L. E. KEARNEY

M. E. KENNEDY

L. E. LUDEKENS

NEWTON MONK

W. M. CAGNEY

E. A. MILLER

J. R. NEUBAUER

C. B. PLUMMER

J. S. STOVER

W. J. WEISZ

W. M. RUST, JR.

K. J. WORTHEN

Ex-Officio:

IRE TRANSACTIONS®

on Vehicular Communications

Published by the Institute of Radio Engineers, Inc., for the Professional Group on Vehicular Communications, 1 East 79th Street, New York 21, New York. Responsibility for the contents rests upon the authors, and not upon the IRE, the Group or its members. Individual copies available for sale to IRE-PGVC members at \$1.60, to IRE members at \$2.40 and to nonmembers at \$4.80.

COPYRIGHT ©1959 — THE INSTITUTE OF RADIO ENGINEERS, INC.

All rights, including translation, are reserved by the IRE. Requests for republication privileges should be addressed to the Institute of Radio Engineers, 1 East 79th Street, New York 21, N. Y.

PRINTED IN THE U.S.A.

TABLE OF CONTENTS

Investigation of Antennas for Two-Way Mobile Communications in the VHF and UHF Regions.....	E. F. Harris	2
Antenna-to-Mast Coupling in Communication.....	M. W. Scheldorf	5
Identifying 450 MC Interference Using a Tunable Receiver and a Panadapter.....	R. J. Klein	13
Transmission Tests on a Trial System of Telephone Service for Aircraft.....	R. V. Crawford	20
Shadows of the Future in Vehicular Communication.....	D. C. Pinkerton	27
A New Era in Communications Through Transistors.....	W. J. Weisz	35
Bias Considerations in Transistor Applications to Communications Circuitry.....	A. G. Manke	47
Transistorized Power Supplies for Higher Input Voltages.....	L. S. Pearlman	54
The Use of Miniature Tubes in Class C Circuits.....	A. Dzik	58
Application of Vehicular Communications to Railroads.....	L. R. Thomas	62
Selective Signaling in the Bell System -- Relay to Transistor...	W. G. Chaney	67
A Transistorized Selector Device for Bell System Mobile Telephone Service.....	J. R. Scantlin	71
A Digital Selective Signaling System for Mobile Radio	J. H. Green and J. Gordon	74
New Ruggedized Hand-Held Microphone for Mobile Radio Equipment	A. Brouns, G. Salisbury and R. Troxel	86

"Problems of Communication Receiver Design Arising from Fluctuating Supply Voltage," by N. H. Young and D. I. Himes, was not received in time for publication in this issue. If received, it will appear at a future date.

"Factors Affecting the Implementation of the New FCC Split-Channel Regulations," by Curtis J. Schultz, is not printed here. PGVC members are referred to the 1958 IRE Wescon Convention Record, Part 8, pages 53 to 60, "Effective Split-Channel Utilization -- A Challenge to the Communication Systems Engineer," by Mr. Schultz.

Mr. William H. Watkins, Engineering Assistant to FCC Commissioner T. A. M. Craven, was scheduled to speak at the conference on a review of 1958 activities in the Commission and a glimpse of what lay immediately ahead. Unfortunately, due to illness, Mr. Watkins was unable to make the presentation. He advises that the material is no longer timely as many trade journals carried equivalent reports at the turn of the year.

INVESTIGATION OF ANTENNAS FOR TWO-WAY MOBILE COMMUNICATIONS IN THE VHF AND UHF REGIONS

Edward F. Harris
Mark Products Company
Morton Grove, Illinois

Summary -- Due to the nature of two-way mobile communications the normal requirement is for base station antennas, as well as the vehicular antennas, to have radiation characteristics which are omnidirectional in azimuth. It is therefore necessary first to investigate the spatial distribution of energy and then to investigate means for confining the radiation in the elevation plane so far as possible to that region of space which represents the path for communication. Scale model techniques have been employed using 1/20 scale automobile mounted on a turntable ground plane to yield useful radiation pattern information for the mobile unit. Data are given for the quarter-wave roof mounted whip antenna and a bumper mounted coaxial antenna, plus a colinear array. For the base station, as well as the mobile unit, it is pointed out that the majority of communication takes place within one degree of the horizon. Pattern shaping techniques and tower and pole mounting effects are shown for various situations of side tower mounted arrays, both to allow for the tower consideration in those systems where side of tower mounting is a necessity and to enable the designer to take advantage of tower shaping situations where they can be used to increase gain in the desired directions. A newly developed three wavelength aperture colinear array for the vehicular unit for the 450 mc range is described. This unit is approximately 6 feet long over-all and tests indicate a great improvement in systems performance over standard quarter-wave whip or dipole type antennas.

When the mobile services were confined to frequencies below 30 mc, the antenna problem was mainly one of providing enough physical length to obtain a reasonable degree of radiation efficiency. Pattern considerations were secondary and almost nonexistent since there was little choice in the mode of operation.

The move to higher frequencies in the 150 mc region came as the mobile services were about to experience a large expansion, and vehicular antennas seem to have evolved from their low-frequency predecessors to the familiar quarter-wave roof mounted whip. Recently, units such as the bumper mounted coaxial dipole have seen application, but so far as is known there has been no real effort to investigate thoroughly the pattern properties of those in general use with a view toward an evaluation of system efficiency.

At this time the field is about to experience another expansion to still higher frequencies in the 450 mc region. Early experimenters have carried the old antenna techniques a step further and are employing the quarter-wave whip antenna with fair results. The physical length of this unit is now about 6 inches over-all and it becomes appar-

ent that some means of increasing the aperture and thus gain is generally to be desired. The physical length of an 18 inch whip has been well accepted and it is possible that even longer units would not be objectionable from an appearance standpoint.

This paper approaches the antenna problem from the standpoint of an analysis of systems in use today with the thought that an understanding of the properties available at the present state of the art will point the way to avenues of attack in an effort to improve performance. Such antenna design work is now feasible in view of the small wavelengths involved and the opportunities for the antenna engineer to exercise his ingenuity are unlimited.

The problem generally involves vertical polarization exclusively, omniazimuth coverage in general, with land station to mobile unit and mobile unit to mobile unit communications. Figure 1 shows the generalized coordinate system used and the positioning of the mobile unit and antenna within the coordinates.

In considering the primary coverage area of a central station communicating with mobile units, refer to Figure 2 which shows a simplified flat earth consideration of the path of propagation. Although the direct and reflected ray are to be considered, the important point is that at ranges over a mile, communication via the direct ray takes place within an angle of plus or minus one degree from the horizon.

In a service that requires uniform or omniazimuth coverage, the only avenue for the increase in gain is that which narrows the beamwidth in the vertical or θ plane. To provide for the analysis of arrays which might produce a narrow vertical pattern, and also illustrate the effects of beamwidth in the vertical plane upon the gain for the

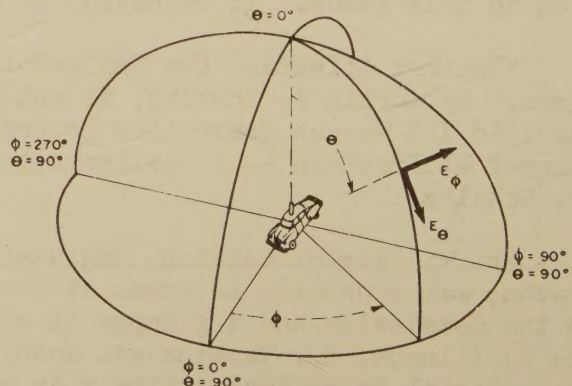


Fig. 1

omniazimuth radiator, Figure 3 has been prepared. A hypothetical radiation pattern has been assumed which is completely omniazimuth in its radiation and furthermore its vertical pattern is uniform between specified limits (θ_1 to θ_2) and then drops off immediately to zero beyond these limits.

This radiator will be termed to have an iso-vertical pattern which is unattainable in practice but is very convenient for analysis. The table in Figure 3 permits evaluation of the theoretical system gain to be expected under several conditions of reduction in the total vertical beamwidth of the omniazimuth radiator.

From the data shown in Figure 2 it may be concluded that it is entirely practical and desirable to confine the radiation within 10 degrees or even less. Such a radiation pattern should produce somewhat over 8 db gain over a dipole. In practice an array which produces a 10 degree vertical beamwidth would not be isovetical by any means and its actual gain must be evaluated by other means. Figure 3, however, is an excellent guide in the discussion of system improvements by restriction of vertical radiation.

Radiation patterns of mobile units have been investigated by conventional scale model tech-

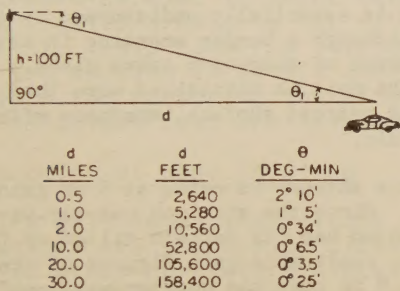


Fig. 2 - Over flat earth, most direct-ray communication occurs within one degree of horizon.

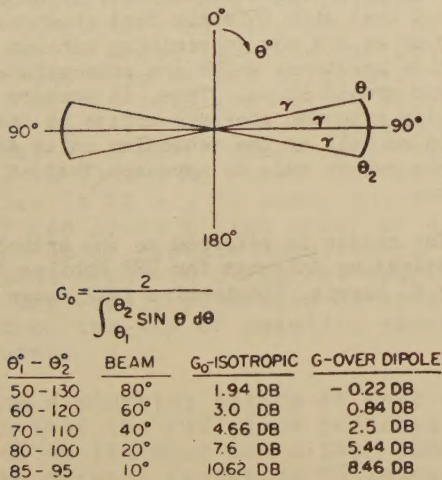


Fig. 3 - Gain analysis for hypothetical omniazimuth isovetical radiator.

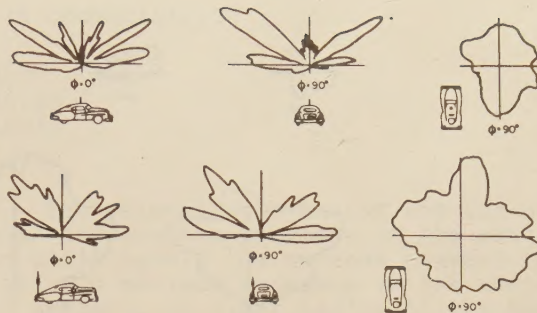


Fig. 4 - Typical patterns of roof-top quarter-wave and bumper-mounted coaxial vehicular antennas scaled 20 to 1.

niques. The average automobile is about 20 feet long. A scale model auto was obtained at the local dime store which was 1 foot long or 1/20 the full size. Therefore, a scale frequency of 20 times 150 or 3,000 mc was employed (9,000 mc for the 450 mc band) for the model pattern measurements.

The auto was mounted at the center of a large ground plane and both the quarter-wave whip and the rear bumper mounted coaxial dipole were modeled and measured. There are limitations to this technique in that the ground plane is finite and that the conductivity of the ground has not been modeled perfectly; however, surprisingly good results were obtained. The measurements shown are necessarily a first approach to the problem.

The photographs show the model auto in position on the ground plane and the assembly mounted on the tower for measurements. Figure 4 contains sets of the principal plane patterns for the two cases of the roof-mounted quarter-wave whip antenna and the bumper-mounted coaxial dipole. These are relative patterns in that the relative values of voltage are recorded at each angle. Note that in both cases a large proportion of the radiation is propagated at the higher angles and that a rather small part is in the useful directions as shown in Figure 2.

To reduce the data to an absolute basis so that actual gain figures may be assigned to the patterns it is necessary to take a complete set of integration patterns to show the space distribution of radiation. This has been done for the case of the roof-mounted quarter-wave whip antenna and the set consisting of θ patterns taken for 10 degree steps in θ from zero to 90 degrees is shown in Figure 5. Referring to the $\theta = 90$ degree pattern of Figure 5, the gain of the pattern varies from 1.1 db above a dipole at the maximum of the pattern to 6 db below a dipole at the minimum point of the pattern. These figures of gain result from planimeter integrations of the θ pattern areas and the proper numerical summations to reduce the pattern data to absolute values. Due to the high angle radiation and the power lost at these unusable angles, the gain in the $\theta = 90$ degree plane (the azimuth or horizon plane) suffers considerably. The fact that the pattern is not perfectly circular

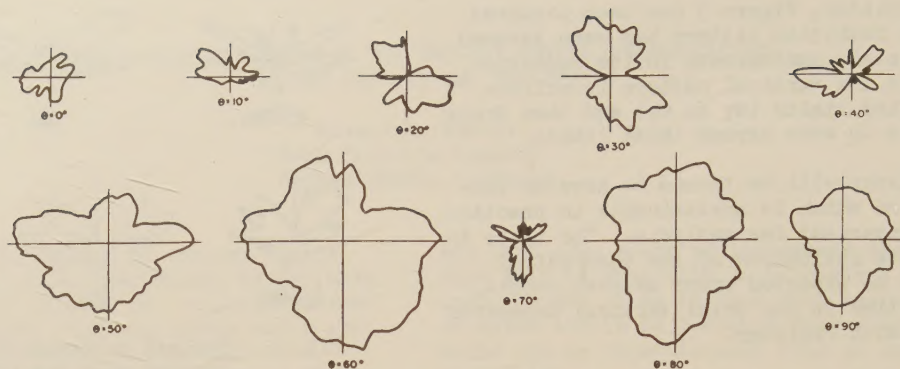


Fig. 5

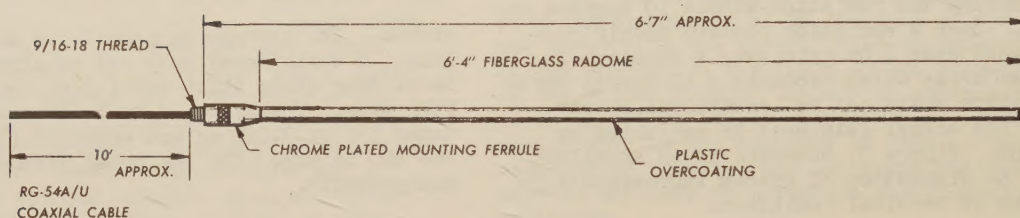


Fig. 6

is of secondary importance since there is appreciable radiation in all directions of azimuth. However, the fact that the level is down due to the higher angle radiation is a serious consideration in design.

On the basis of the data presented it is felt that proper design of the mobile-mounted antenna can produce effective gains over presently used systems of the order of 6 to 10 db at those angles which are effective in the communication zone. From past experience it is known that the factors causing high-angle radiation will become more severe at the new 450 mc range than at the 150 mc range studied so that the need for improvement of the vehicular antenna system becomes even more important and the possibilities for improvement proportionately greater.

The antenna as shown in Figure 6 represents recent design in an effort to effect a substantial improvement of performance of the vehicular unit at 450 mc. The radiating aperture consists of cophased elements approximately three wavelengths in extent. Over-all the unit is approximately 6 feet and 7 inches.

This antenna produces an omniazimuth pattern with an elevation beamwidth of 18 degrees between half power points. When mounted on a vehicle in

such positions as rear fender or truck roof, its pattern is essentially undisturbed by the vehicle. Although a bumper mounting is satisfactory, some degree of shadowing takes place. If, however, the unit is maintained more than six inches from the nearest surface impedance effects are negligible.

This antenna is rated at 5 db gain over a dipole. Since the six-inch quarter-wave whip roof top mounted has its pattern tilted up from the horizon, realizable gain figures of the order of 7 db to 8 db over the quarter-wave roof top whip are consistently measured. This, of course, represents a substantial improvement in both talk out and talk back range of a system.

From an aperture standpoint, it becomes apparent that with this six-foot extended aperture at 450 mc we are now approaching antenna sizes and effective apertures which are commonplace in the low band around 40 mc. Thus, it appears that by utilizing extended aperture arrays at the base station as well as the vehicular units system performance may be made to approach that of low band systems.

The reader is referred to the article, "Investigating Antennas for UHF Mobiles," by Edward F. Harris, Electronics 1952, page 127.

ANTENNA-TO-MAST COUPLING IN COMMUNICATION

M. W. Scheldorf
Andrew Corporation
Chicago, Illinois

The use of vertically polarized antenna systems in the communication industry has been standard for quite a period of time. This standard results in a major part from the need for omnidirectional patterns with mobile stations and the fact that this solution is made in the simplest most direct manner by using a vertical conductor mounted over some metallic surface of the vehicle. In this application the vehicle surface becomes a very satisfactory horizontally disposed reflector and the operating structure becomes fundamentally what is known as a ground plane antenna. That this choice of polarization places a handicap on the design of the station antenna is not a commonly well known fact. The problem in this connection arises from the inability to provide relatively large conducting ground plane surfaces at the top of tower structures used to mount these antennas at suitable heights for effective propagation. This paper is intended to discuss the problem in detail and to describe tests for measuring the effectiveness of solutions that are developed.

Character of Mast Coupling

It is well known that linear antenna conductors are especially closely coupled to other conductors placed parallel and near to them. Use is made of this property in the construction of unidirectional antenna arrays commonly employed in TV reception and for amateur radio communication. In general there is considerably less coupling between colinear conductors but the magnitude is sufficiently great to cause serious trouble for the case we are to study. As an example we can cite the mutual impedance between two end-to-end half wave dipole antennas. The self impedance of each antenna is $73 + j 42$ ohms. The mutual impedance is $26 + j 20$ ohms, which obviously can cause a high order of disturbance under certain conditions. These conditions occur in different degrees as simple vertically polarized antennas are mounted on the top of metallic support structures.

The disturbing nature of mast coupling is that the radiation produced by currents on the mast can either combine with the antenna radiation to improve the antenna system or it may cancel some of the antenna radiation and detract from the normal capabilities of the antenna.

The natural problem for the designer is to prevent the coupling to the mast and still permit the antenna element to display a maximum response in the vertical pattern, at right angles to the mast, i.e., on the horizon where the signal becomes most effective in propagation to some remote location.

There is a great variety of antenna elements which have been employed to serve this purpose but our present discussion will deal with the ground plane antenna since it represents the most extensive application in our experience (the unipole antenna), and one which we have studied most thoroughly.

In the practical construction of ground plane antennas the surface which the title refers to is replaced by a number of radially disposed rods. It has been generally found that four such rods suffice to give performance essentially equivalent to a solid sheet. It has also been generally accepted that these rods should be in the order of a quarter wavelength in length (effective ground plane diameter equal to a half wavelength).

In the application of these antennas we have found that a percentage of our customers have experienced unusual conditions involving the distance that the antenna is mounted above the tower top (which to the engineer represents a variation due to the height of the antenna above the ground surface). This variable is not to be confused with the change in performance due to the change in the propagation path. It is entirely a function of local conditions and we have been able to show that it is a matter of coupling between the antenna and the support.

Laboratory Studies of Mast Coupling

The nature of the mast coupling can readily be demonstrated in the laboratory by a study of a series of vertical patterns. The antenna used is a conventional ground plane antenna with quarter wavelength ground rods. In order to measure the vertical patterns, the antenna proper is placed with its axis in a horizontal plane and excited from a source far enough away to place the entire antenna system in a substantially uniform field. The specific distance from the source and the characteristics of the source are indicated by simple relation-

ships well known to those familiar with pattern-taking techniques. The position normally occupied by the mast is taken by a telescoping tubular member of substantial cross-section as indicated by the setup diagram of Figure 1.

Under the conditions of this test, any radiation which passes the ground plane and excites the mast stub will make the latter behave like a second antenna element. A standing wave will be set up on the mast stub, with zero magnitude at its end as in the case of any linear antenna element. The magnitude of the current that flows in the mast stub, is controlled by the degree of isolation produced by the ground plane. The phase of the current is controlled by the distance of the end of the mast stub from the ground plane, i.e., by the length of the stub. The total radiation from the two antennas is for this reason a function of the length of the stub (provided the ground plane permits some radiation to pass from the antenna proper to the mast stub).

Measurements were made at 74 MC on a completely isolated antenna so that there would be no trouble from currents on the

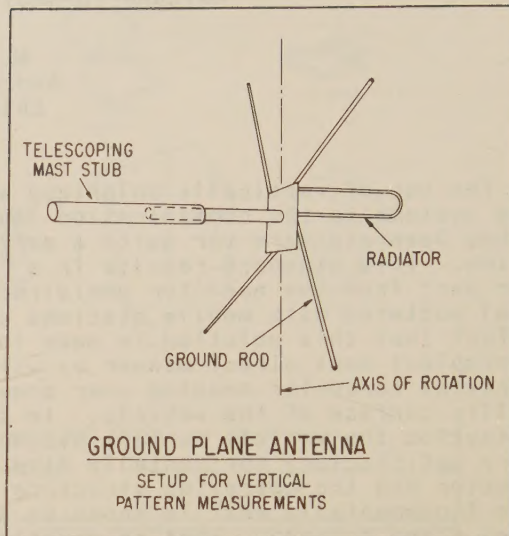
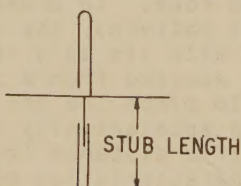
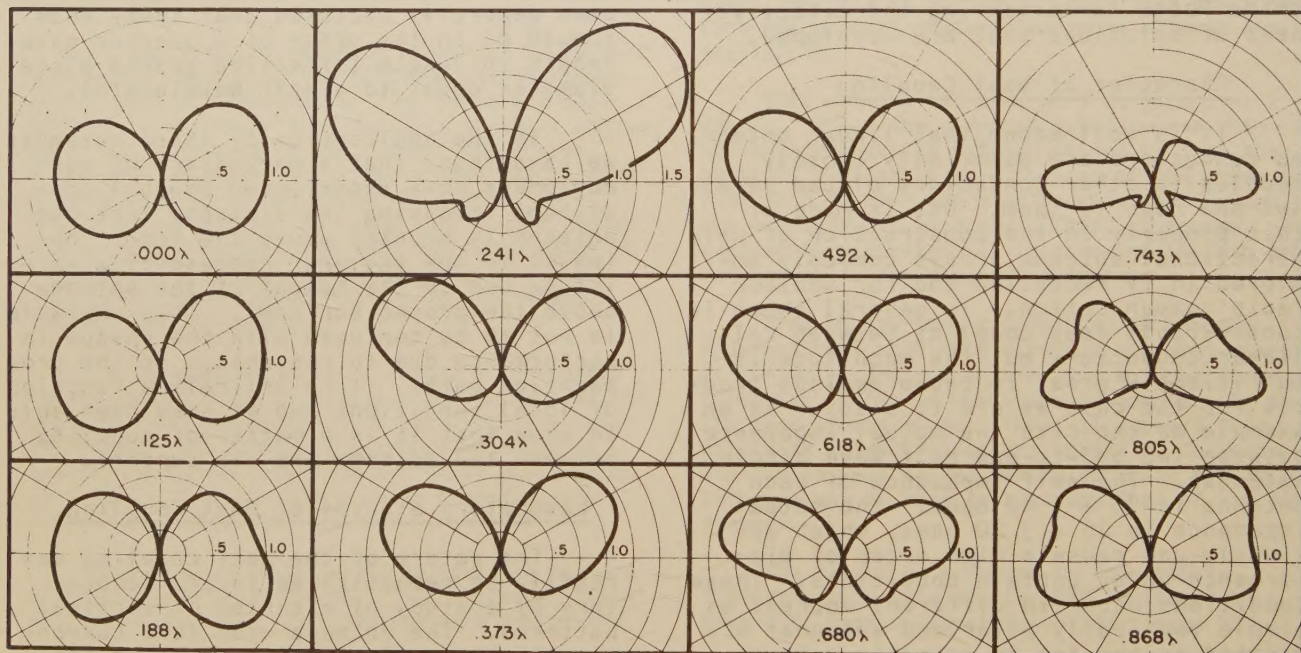


Fig. 1

connecting cable. A detector was mounted right at the antenna and the associated indicating instrument was read by a telescope. Figure 2 shows a series of measured vertical patterns for a range of mast stub length from zero to 0.87 wavelength. For gain calculation and appro-



VERTICAL PATTERNS
GROUND PLANE ANTENNA
WITH ADJUSTABLE STUB MAST.
74 MC.

STUB LENGTHS ARE INDICATED.
PATTERN MAGNITUDES ARE
RELATIVE FIELD STRENGTH.

Fig. 2

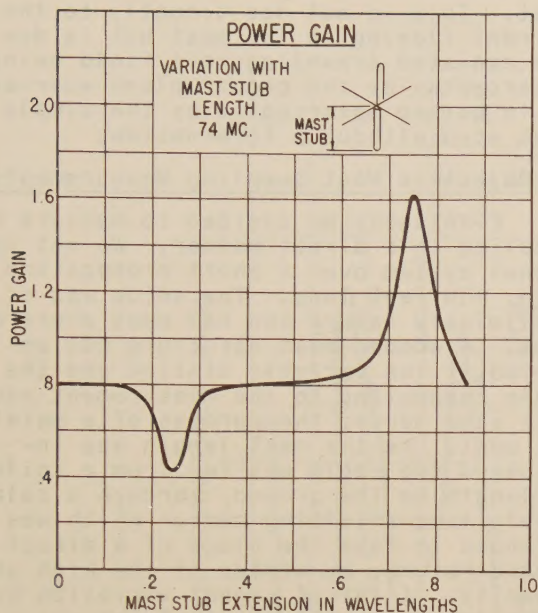


Fig. 3

appropriate comparison reasons these curves are all plotted with a uniform field value in the direction of the horizon. It will be noted that the strongest radiation beam oscillates above and below the horizon as the mast stub length is increased, the beam position being determined by the magnitude of the current excited in the mast stub and by its phase relationship with respect to the antenna current. As the mast stub length is increased, the radiation pattern also develops a higher order shape, corresponding to the increased over-all radiator length.

A rough measure of the effective horizon gain of this system as a radiator, can be obtained by observing the areas included within the patterns. With a mast stub length of 0.241λ the area is very large, indicating low gain. With a mast stub length of 0.743λ the area is small, indicating high gain. Integration of these patterns reveals the gain values shown in Figure 3. This curve shows the critical stub lengths where the normal antenna gain is seriously reduced or appreciably improved.

In making extensive studies of the mast coupling properties of an antenna by the above method one will automatically look for schemes to avoid the laborious procedure of taking individual patterns for a series of mast stub lengths. This is especially true when it is desired to cover a band of frequencies with a fixed antenna structure.

The fact that the effective gain of the antenna system varies considerably

suggests an alternate system, which eliminates much of the work. The antenna is placed in the same position as employed for the pattern measurements but in a fixed azimuth angle so that the pattern field exciting antenna is located on the horizon. Now when the mast stub length is varied, the response at the antenna under test is proportional to its gain. One may suspect an effect of the change of impedance of the test antenna, but this is very small as will be seen from the experimental data.

In Figure 4 we have shown the results of a simplified coupling test with the ground plane antenna. Similar tests for effective power gain by the earlier method are shown in Figure 5. The correlation is indeed satisfactory. These particular tests were made at a scale frequency of 465 MC so that we could obtain mast stub extensions of great length without unduly long physical members. Also the radiator is not a folded element and the conductor cross-sections were much greater, which may help to account for the differences between these curves and that of Figure 3, in the region where they overlap.

Interpretation of Laboratory Tests

The remaining problem is to bridge the gap between these laboratory tests and the practical application in the field. It may be seen that we suffer a very wide range of apparent antenna effectiveness when the mast stub is varied in the manner we have described. On the average it is considered quite satisfactory to use

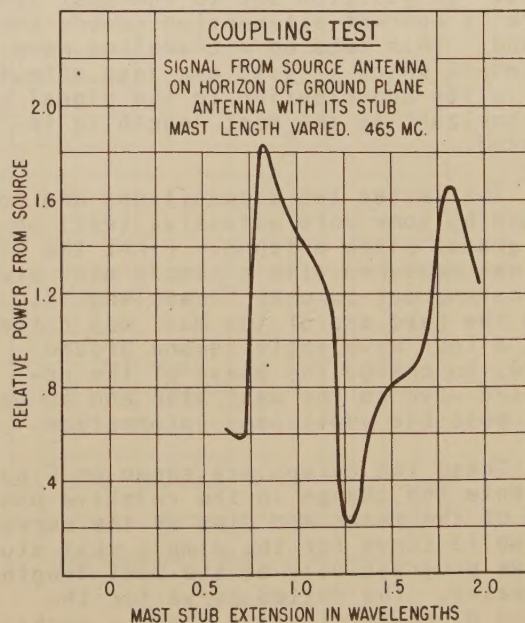


Fig. 4

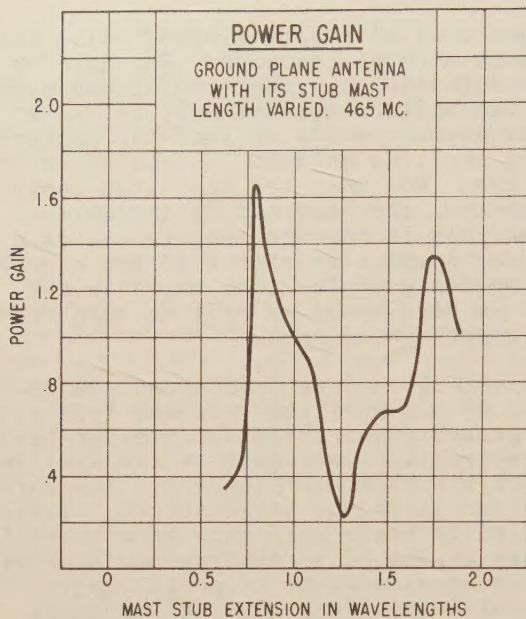


Fig. 5

ground plane antennas with ground rods only a quarter wavelength long. The curves that we have shown so far would seem to contradict this, but subsequent data will show that the above tests were not made under properly simulated conditions.

Immediately we have begun to suspect that an antenna in its operating position would not suffer from these same wide variations. Part of this is due to ground absorption. Currents on the real mast are not reflected completely at the ground so a reduced value standing wave is produced. In addition due to the mast length there is current attenuation toward the ground. This sets up a traveling wave component which is less and less effective in its contribution to the signal on the horizon, as the mast length is increased.

The latter two suppositions are confirmed by some more extensive tests on the ground plane antenna. First the signal was measured with a simple mast stub extension, out to over 6 wavelengths. Then the base end of the mast was fitted with a four wavelength square ground plane, to change the phase of the reflected wave on the mast stub and to gain some possible additional information.

These two curves are shown on Figure 6. Note the change in the relative position of the peaks and dips of the curves. The solid curve for the simple mast stub, decays progressively as the mast length increases. The dotted curve for the ground plane termination shows a marked increase in the reflected current on the

mast. This is not due directly to the current flowing on the mast but is due to the radiated traveling wave field being intercepted by the ground plane whereas it is not so intercepted by the simple mast stub without a termination.

Objective Mast Coupling Measurements

Eventually we decided to measure mast coupling in a direct manner. We set up a signal system over a short propagation path, 450 feet long. The setup was of a preliminary nature and had many shortcomings. A wooden mast structure was employed at the variable station and the cable connecting to the measurement equipment also served the purpose of a metallic mast. As the mast length was increased the cable was fed from a coiled up length on the ground, through a relatively long shielding member which was intended to take the place of a direct ground return, by virtue of the high shunt capacity. A lot of signal variation was experienced due to motion of the suspended cable from the wind, and due to unwanted fields picked up in the area of the unused cable length. We also found that the physical position of the antenna supports, had to be chosen by trial due to the effect of the intervening terrain on the signal variation with height. In making these choices we were limited by the fact that the variable antenna had to be mounted on a tall existing telephone pole which was not desirably suited to a smooth propagation path.

In spite of these handicaps we were able to obtain enough data to substantiate our earlier suppositions. Figure 7 shows two mast coupling curves. The first is for a corner-reflector which has inherently low mast coupling because of its radiation away from the reflector surface. The second is for a ground plane antenna which has definitely some degree of mast coupling because of its finite size ground plane. The antennas are to be compared by noting the average of the variation of the curves from a smooth one rising slowly with antenna height. On this basis we arrive at figures of merit of 0.25 db and 1.3 db for the corner-reflector and ground plane antennas respectively.

Measurements were made on a variety of typical antennas for communication service. These measurements were made in the center of the 450-470 MC band. A series of curves were taken in the manner indicated in Figure 7 to give the objective mast coupling results. These antennas were then tested in the laboratory for gain variation in the manner indicated in Figure 3. A comparison of the resultant data is shown plotted in a sort of calibration curve, Figure 8, which in-

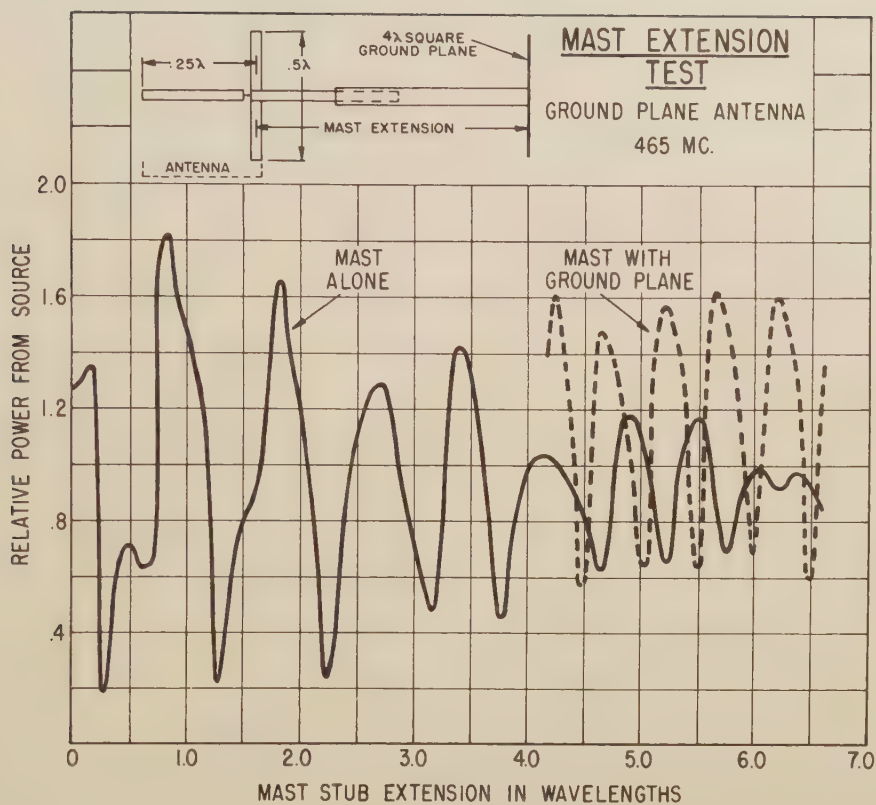


Fig. 6

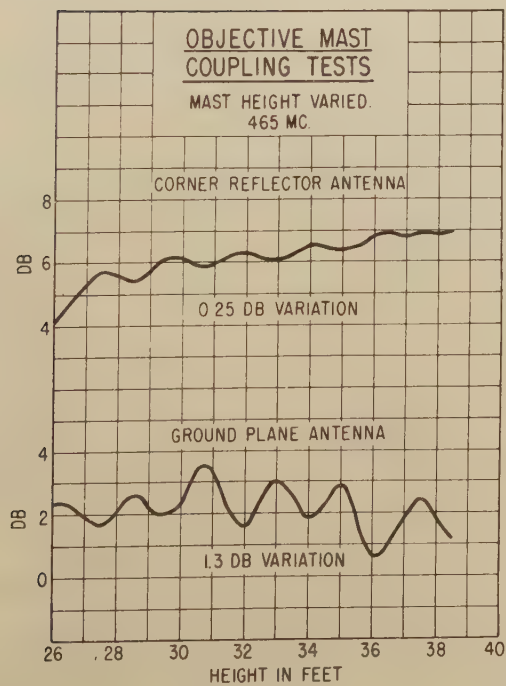


Fig. 7

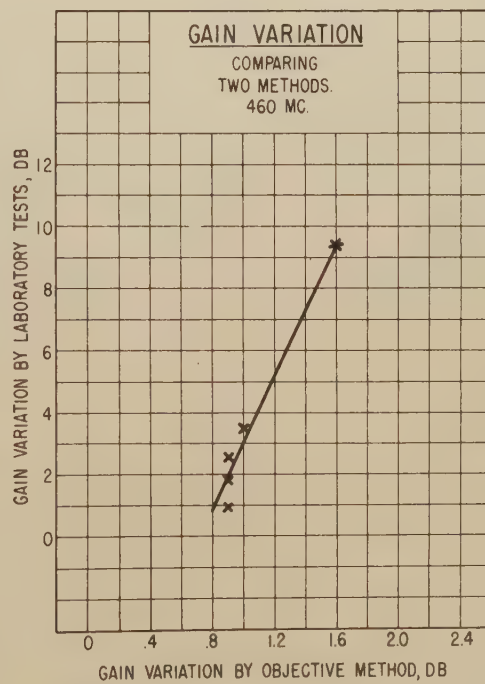


Fig. 8

dicates the nature of gain variation that can be predicted from laboratory tests. This curve serves to demonstrate the character of the exaggerated variations that the laboratory tests produce, as we predicted earlier.

Improved Objective Measurements

A much more elaborate and permanent objective mast coupling setup has been completed and put into operation recently. One of the serious problems with the first setup is the effect of the terrain and soil on the propagation. This is the result from having elevated antennas at both ends of the system. We have two paths for the signal, one directly through the air and another by way of a reflected wave from the intervening ground surface. Irregularities in the ground surface and changes in the character of the surface material contribute to the propagation in a varying manner, as the height of one antenna is varied.

We have overcome this handicap by placing the source antenna on the ground so there is a minimum of ground reflected wave. This antenna is a half parabolic

cylinder antenna as shown in Photograph 1. A large ground plane surface is used in connection with half of a folded dipole antenna (similar to those used in our unipole antennas). This folded antenna element is converted into a conventional paraboloid antenna feed, by placing an adjustable reflector rod a quarter wavelength in front of the antenna element. Rods over a half wavelength long form the main reflector surface.

This antenna was found to give about 10 db gain over the simple antenna over a ground plane. This gain was needed in order to overcome the effect of the extremely low antenna height provided by the antenna system position.

Difficulties with the movement of the suspended cable and with control of the vertical motion of the antenna under test, were overcome by a telescopic structural arrangement. Two channels were welded together to form a hollow guide. An I-beam was mounted within this guide so as to form a telescoping combination. The connecting cable was mounted next to the web of the I-beam and fed down through the guide so as to be rigid throughout its

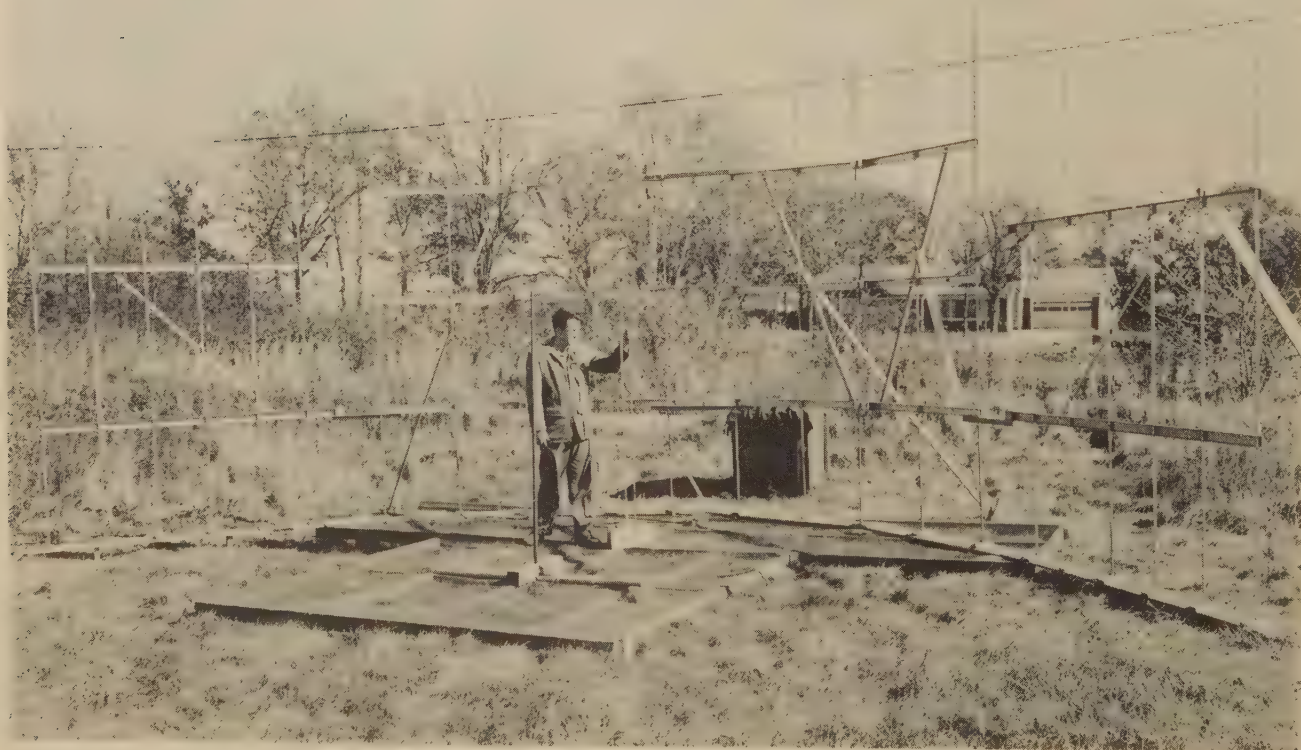


Photo 1 - Source antenna for objective coupling tests.



Photo 2 - Objective antenna coupling test setup.

exposed length and shielded over that part of its length that is variable when the antenna is elevated.

In order to place the antenna so that the horizon is directed toward the source antenna position at the average elevated position of the former, the telescoping structure was tilted toward the source antenna position. This detail and others are shown in Photograph 2. The telephone pole serves only to support the climbing ladder. During construction it also provided a means for hoisting the members forming the telescoping structure and its supporting braces.

Connected with the telescoping structure is a shielded room, which serves

to house the unused portion of the connecting cable. In this way there is no pickup on this cable and the signal received from the test antenna is stable.

By choosing to place the source antenna on the ground and by going to a reduced distance of 200 feet, we were able to select a very flat and uniform propagation path.

Antenna Coupling Standard

One of the most important steps in this program is to establish a reference from which to judge new antenna structures. This was done by measurements of the coupling for a ground plane antenna with various ground rod lengths. These

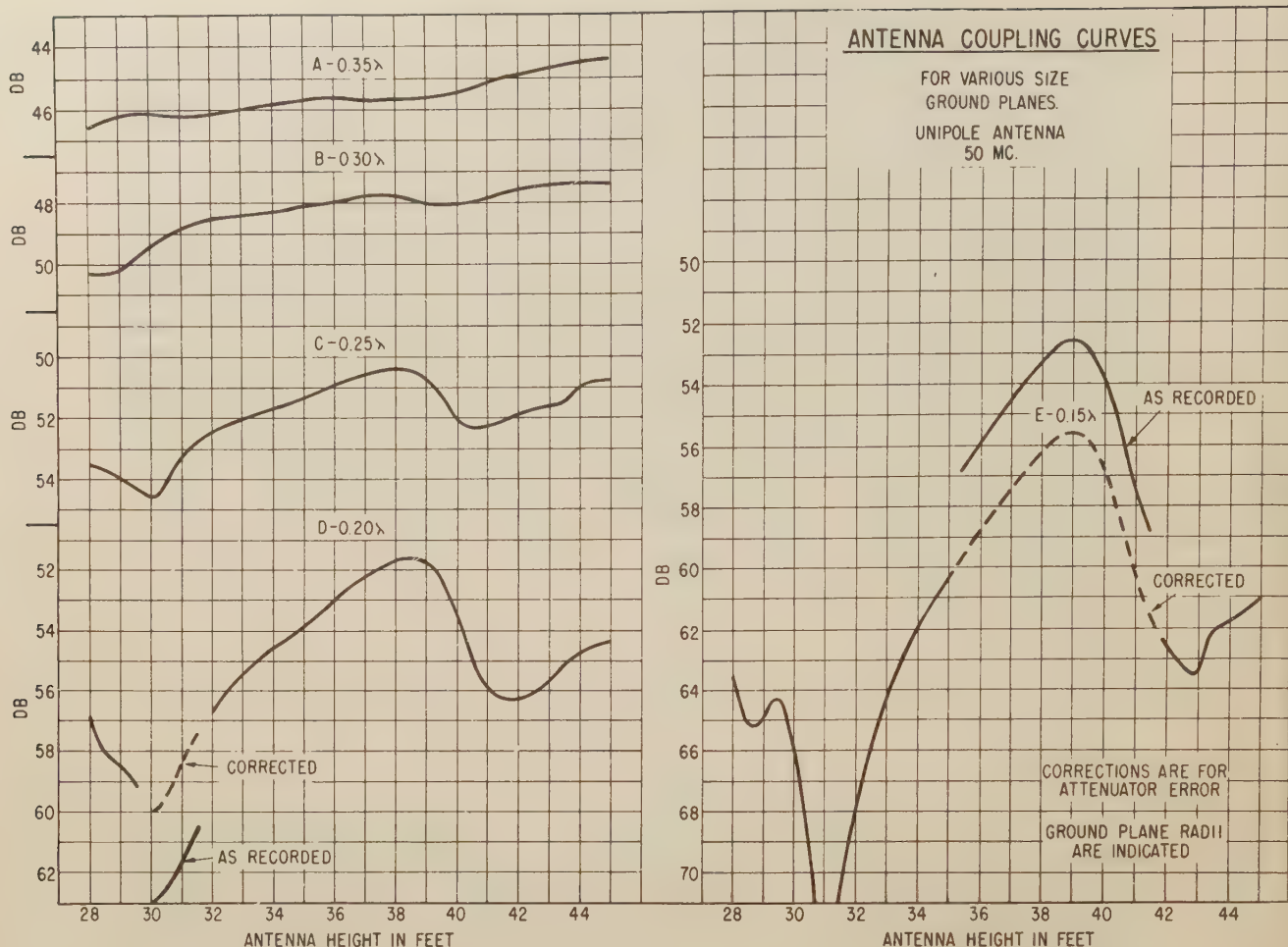


Fig. 9

curves are indicated in Figure 9. There is only a slight improvement in mast coupling when the ground rods are lengthened beyond the normal $\lambda/4$ but a rapid serious change to a worse condition when the rods are shortened.

We have chosen to select for our standard, a mast coupling curve equivalent to curve C, or better.

Conclusion

We have described methods for testing for the presence of mast coupling in the laboratory. The relation between these measurements and more objective tests in the field have been demonstrated. Final objective type measurements, with a standard reference have been established.

IDENTIFYING 450 MC INTERFERENCE USING A TUNABLE RECEIVER AND A PANADAPTOR

R. J. Klein
Illinois Bell Telephone Company
Chicago, Illinois

Summary

Many mobile systems operating in the 450-470 mc. band are troubled by radio interference. Much of this interference is caused by intermodulation and spurious radiation from other systems operating in the same geographical area and frequency band. Due to the nature of intermodulation and spurious radiation interference, any intelligence originating from the interfering stations is obscured. This makes it impossible to identify them. If the stations causing the interference cannot be identified, it is difficult to take steps to eliminate the interference.

This paper describes how a 450-470 mc. tunable receiver and Panadaptor can be used to identify interference. By scanning the band visually and aurally in 200 kc steps, the fundamental frequencies of the interfering stations can be found. Knowing these frequencies, the stations can be identified.

Introduction

Many people engaged in maintaining mobile communication systems in the 450-470 mc. band have encountered radio interference and we at Illinois Bell Telephone Company have had our share. So severe and frequent is some of this interference that a system may be rendered completely useless at times.

We have found that most interference can be reduced to a tolerable level or stopped completely if the source and cause of the interference can be determined. However, finding the source and cause of interference may often be very difficult.

This paper discusses methods that were found helpful in identifying interference affecting mobile systems in the 450-470 mc. band. One method in particular will be discussed at length. This method was used to identify the most difficult types of interference.

UHF Systems Concentration

Let us first look into the reasons why we have found interference in the 450-470 mc. band so much worse than in other frequency bands assigned to mobile radio communications. It actually could be explained simply by saying there are too many radio systems operating in too small of a geographical area. This is not the only reason for the interference; there are many other contributing factors. Since in this discussion we are only concerned with the interference problem in the UHF band let us use

the Chicago downtown area as an example of UHF system concentration. Figure 1 shows a sketch of the Chicago Downtown area. The area shown is about one mile square. The different types of radio systems are shown by various codes. There are approximately 5 TV broadcasting stations, 10 FM broadcasting stations, 40 high and low band VHF mobile base stations, 10 miscellaneous stations such as microwave, HF maritime, radar

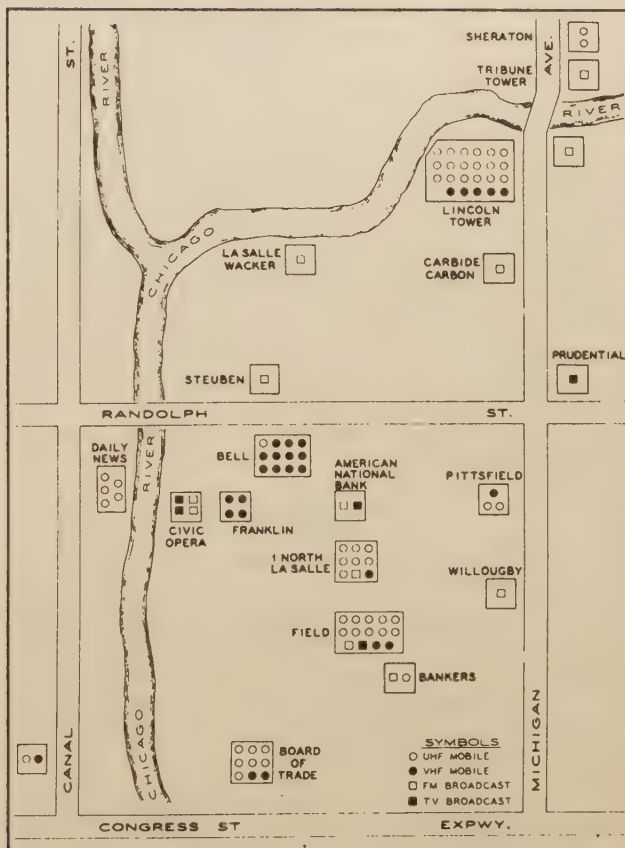


Fig. 1 - Radio systems in the Chicago Loop.

and, last but not least, 60 UHF base stations. UHF systems out-rank all others. With so many systems operating in such a small area intermodulation interference is quite probable. Also any spurious radiation from any one of the stations is very likely to fall on another station's operating frequency and cause interference.

UHF Domestic Public Land Mobile Systems

Illinois Bell has UHF installations on several of the buildings shown in Figure 1 but the location most susceptible to interference is the Field Building. In this building we operate

six UHF Domestic Public Land Mobile systems. Five are in use as regular mobile telephone systems and the sixth is currently being used for telephone communications between land and aircraft under a special experimental and developmental permit.

Some radio systems can tolerate a degree of interference with very little effect on the efficiency of the system. This is not true for Domestic Public Land Mobile systems. Transmission is expected to be as good or better than wire telephone service and this leaves no room for radio interference. In this type of system both sides of the conversation are transmitted over the base transmitter. If interference comes in on the base receiver while the party on the wire line side is talking, the interference may obscure what is being said.

In this system the mobile indicates to the telephone operator that he wishes to make a call by putting his carrier on the air for about three seconds. This activates the carrier operated relay in the base receiver and ultimately lights a lamp on the mobile operator's switchboard. Seeing the lamp the operator comes in on the channel and handles the call. If, while the channel is idle, radio interference pulls up the carrier operated relay, the operator will go in on the channel only to find that no one is calling her. If these false signals occur often, it is annoying to the operators and needlessly ties up the channel. Thus in our Mobile Telephone Systems very little interference can be tolerated.

Types of Interference

Five types of interference which we have encountered are:

1. Intermodulation between 2 UHF mobile base stations.
2. Intermodulation between a UHF mobile station and the video and aural carriers of a nearby TV broadcast station.
3. Spurious radiation from nearby UHF base transmitters.
4. Radiation from the local oscillators of TV receivers.
5. Unintentional radiation from UHF transmitters being tested into dummy loads.

We have found that a good number of interference cases affecting UHF mobile systems can be handled in much the same way as interference on other frequency bands. If call letters or some other identification can be recognized, the interfering station can easily be identified. If the interference is in the form of carrier only and remains on for a long enough period, a directional antenna can be used to determine a bearing to the interference. A vehicle equipped

with an adequate receiver and antenna is usually needed to ultimately run down this type of interference.

The type of interference that is the most difficult to identify is that which comes in short frequent bursts. We have found most interference of this type results from third order intermodulation product of 2 UHF systems. Sometimes the period of interference is long enough that a word or two may be recognized but usually not enough is heard to give a clue that may lead to identification. Intermodulation usually results in a garbled unintelligible part of two conversations. Because spurious radiation due to parasitics in a transmitter is very unstable in frequency, it causes interference to any one system for only a short period. During this short period it is impossible to receive any information that may lead to identification of the source. In some cases of this type we were able to hear a complete address given and assuming that the dispatcher of the interfering system was sending a vehicle to that address we hurried out to the address ourselves hoping to catch the mobile there. We were never very successful at running down cases in this way. Most of the time the address was heard incorrectly and when we arrived at what we thought was the correct address no mobile radio equipped vehicles were in sight.

Many hours were spent listening to interference believed to be caused by intermodulation or spurious radiation and trying to add up bits of information that could be a clue to the identity of the station or stations causing the interference. Very few cases were solved in this way.

A Method of Identifying Interference

Since it was quite certain that most interference affecting systems in the 450-470 mc. band originated from other systems in the same frequency range a plan was decided on which we felt would help us to identify the sources. The plan was to obtain a tunable receiver that covered the 450-470 mc. band. Good selectivity and sensitivity was desired. The tunable receiver would be located in the same quarters as the system receiver and each time the interference was heard on the system receiver the tunable receiver would be tuned. This procedure would be continued until a signal was heard on the tunable receiver that was found to coincide with the interference. Then, by knowing the frequency of the interfering station it could be identified by referring to a list of stations which we prepared.

Since a receiver meeting the requirements desired was not available a crystal controlled 450-470 mc. converter was constructed. The converter was fed into a Hallicrafters VHF receiver which acted as a variable IF. Figure 2 is a photograph of the converter. The block diagram is shown in Figure 3. The converter employs two

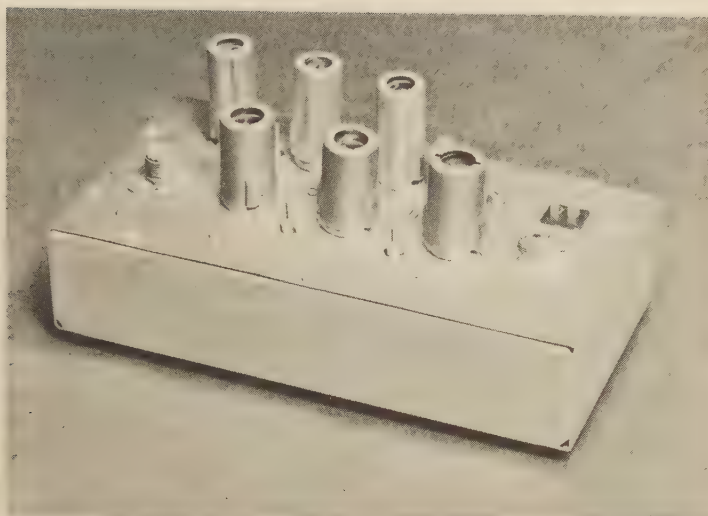


Fig. 2 - UHF crystal controlled converter.

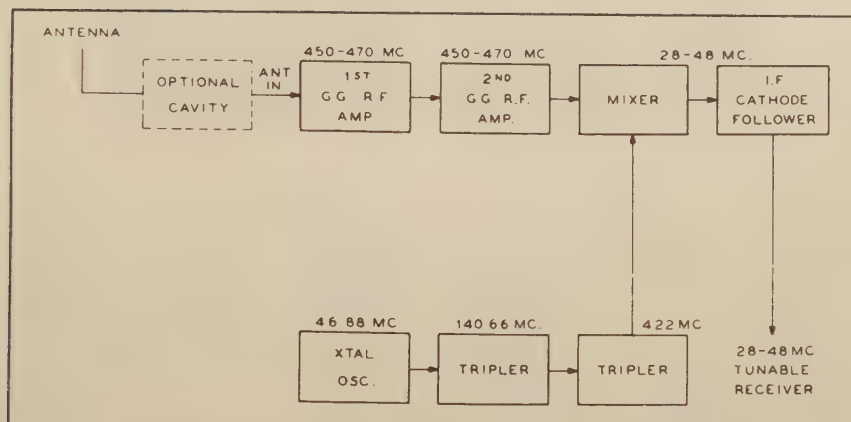


Fig. 3 - Block diagram of uhf crystal controlled converter.

stages of grounded grid RF amplification, a mixer with 28 to 48 mc. IF output and an untuned IF cathode follower. The injection signal is generated by a 46.88 mc. crystal controlled oscillator and two tripler stages multiplying the signal to the desired 422 mc. The over-all sensitivity of the converter and receiver was about 1 microvolt for 20 db of noise quieting.

The converter and tunable receiver were located at the Field Building where we had several unsolved cases of interference and the method was tried out. However, three problems were apparent in using the equipment:

1. Too much time was required to tune the 450-470 mc. spectrum, as the receiver could only be tuned during the interval the interference was present.

2. The converter lacked sufficient front end selectivity to reject strong local FM and TV broadcasting stations. These strong stations appeared all over the dial and very few 450 mc. stations could be heard. These same stations

caused desensitization of the converter so that only the stronger 450 mc. signals could be heard.

3. Since such a large frequency range had to be covered it was quite easy to become impatient and miss a station if the receiver was tuned too rapidly.

The selectivity problem was cleared up by attaching a cavity ahead of the converter. The cavity was broad enough so that about one mc. of the band could be covered before it had to be retuned. The strong TV and FM station were completely eliminated. Now the 450-470 mc. band could be tuned and only signals within that band were heard. In fact we found so many stations operating in this band that it appeared hopeless to tune the band and listen to each station individually each time the interference came on.

We needed something that would allow us to monitor several stations at the same time and still have each station keep its identity as far as frequency is concerned. The only device known

capable of this is the Panadaptor. One was located attached to the tunable receiver and we were in business!

A panadaptor is a device which when connected to a receiver displays each signal within the band on the screen of a cathode ray tube. The signals appear as inverted V's or pips whose amplitude and position along a horizontal calibrated axis indicate signal level and frequency, respectively.

As an example, Figure 4 represents a one megacycle section of the UHF band with stations assumed every 50 kc. Each circle represents a 200 kc. section of the band as seen on the Panadaptor. The center of each circle represents the frequency to which the tunable receiver is tuned.

Lets assume that System "A" at 460.050 mc. is receiving intermodulation interference and cannot identify the stations causing the interference. The tunable receiver, converter and Panadaptor are located at station "A". The receiver is tuned to 460.1 mc. If all the stations operating between 460 and 460.2 mc. are on the air at that time the display such as is shown in circle one will be seen. This section of the spectrum is watched until interference is heard on the System "A" receiver. If the appearance of pips on the CR tube does not coincide with the appearance of the interference heard on the system receiver, the tunable receiver is tuned 200 kc. higher, or 460.3 mc. 460.3 mc. $\pm$ 100 kc. is watched until the interference is heard again on the system receiver. If none of the pips seen coincide with the appearance of the interference the receiver is moved 200 kc. higher to 460.5 mc. Now let us assume that a pip on 460.450 mc., we will call this System "B", appears at the same time the interference is heard on the System "A" receiver. Now we have a suspect. The receiver is tuned to 460.450 mc. and System "B" is monitored both aurally and visually. The chances are that if System "B" is

one of the stations causing the intermodulation interference to System "A" a word or two will be recognized in the interval of interference that can be traced as coming from System "B". Knowing the frequencies of Systems "A" and "B" we find that they are separated by 400 kc. Since third order intermodulation is suspected we can make an assumption that the other station contributing to the interference is 400 kc. higher than System "B", or 460.850 mc. The receiver is tuned to that frequency and we find that the system at 460.850 mc., we will designate it as System "C", comes on every time the interference is heard. Now we have the frequencies of both stations contributing to the intermodulation inference. These two frequencies are compared with a list of systems known to be operating in the vicinity. The dispatchers of these systems are called on the telephone and a positive check is made by having both stations go on the air at the same time.

A station radiating a spurious signal can be located in the same manner except in this case only the one station need be identified.

Figure 5 shows several photographs taken of Panadaptor displays to indicate how actual signals appear.

As you can see, the use of the Panadaptor makes it possible to quickly identify sources of intermodulation interference. In some cases it is possible to track intermodulation interference in about the length of time it takes to describe the process. The equipment worked so well in identifying the most elusive types of interference that some cases that had affected some of our systems for more than a year were identified in just a few hours.

Figure 6 shows the equipment as set up at the Field Building.

Figure 7 shows a block diagram of the equipment. 450-470 mc. signals are fed to the

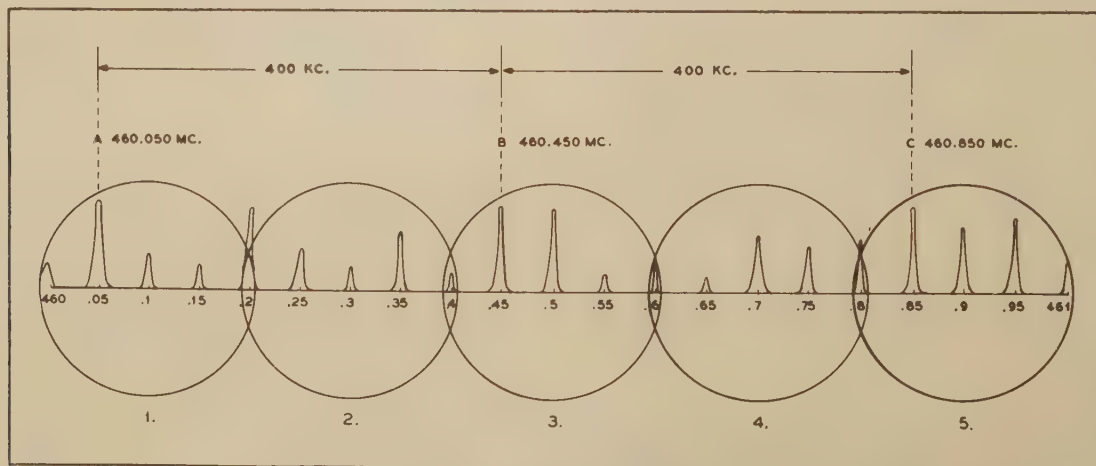


Fig. 4 - Panadaptor displays while scanning a segment of the uhf band (200 kc steps).

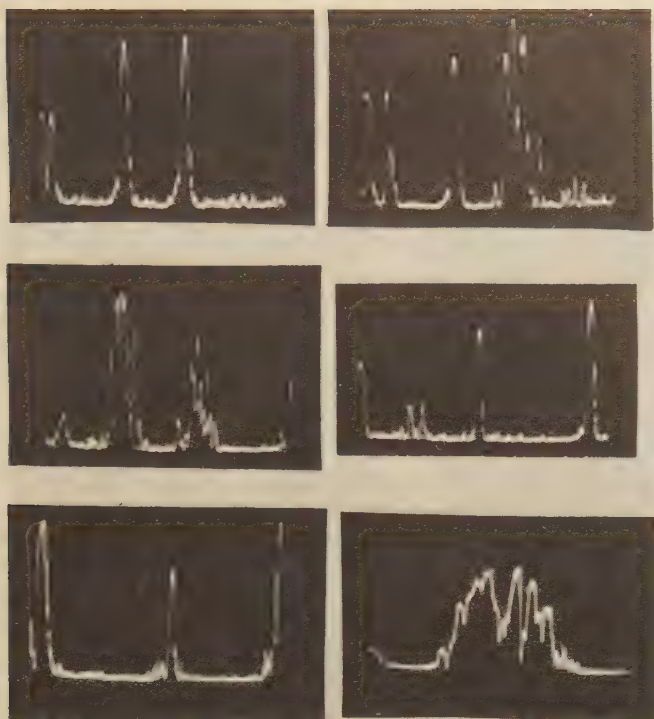


Fig. 5 - Actual photographs of signals as they appear on the screen of a Panadaptor.

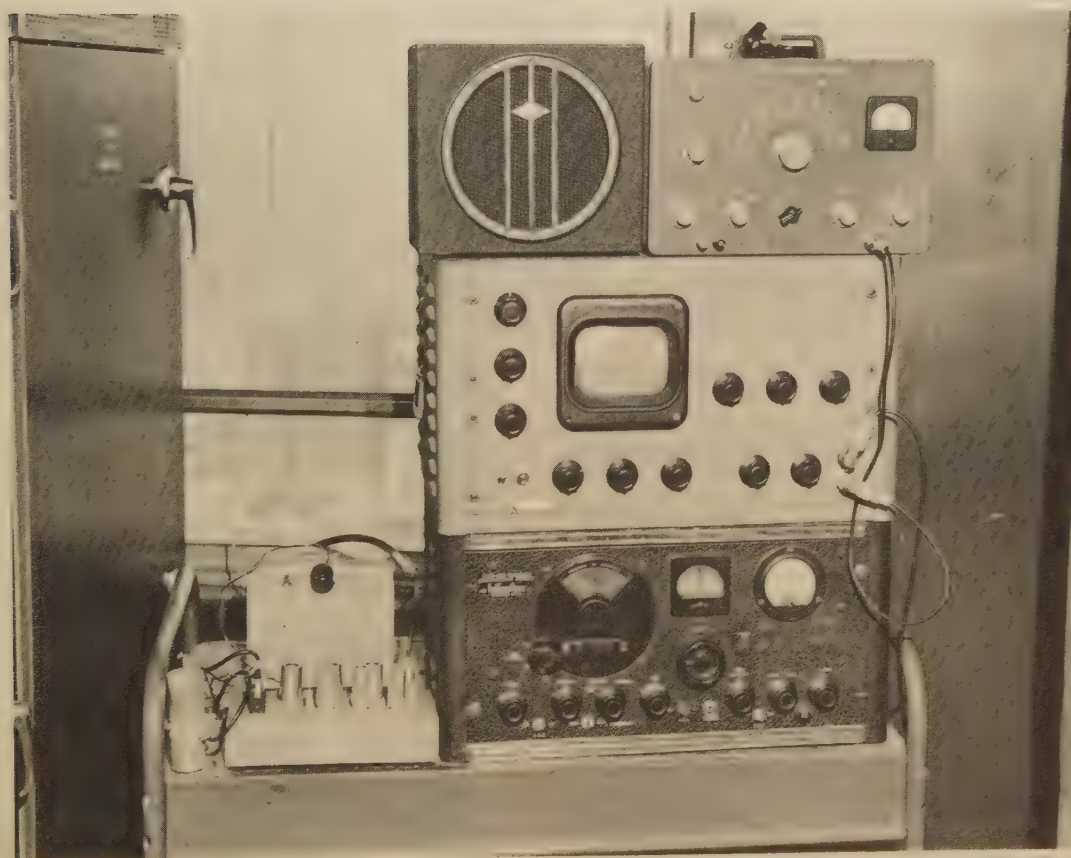


Fig. 6'- Converter, tunable receiver, Panadaptor, and heterodyne oscillator.

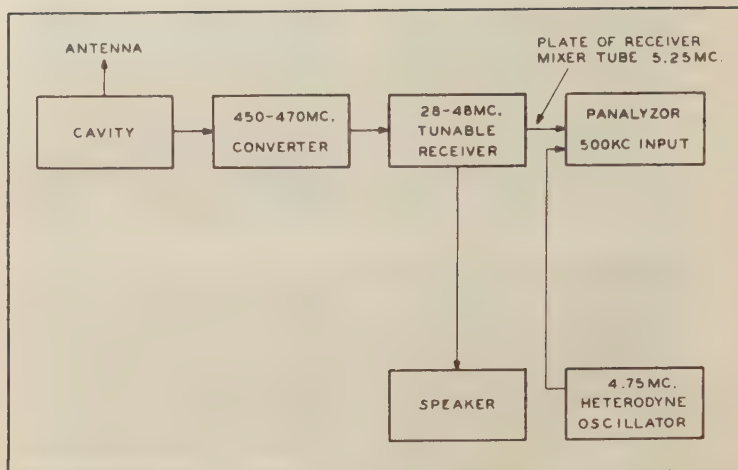


Fig. 7 - Arrangement of equipment (shown in Fig. 6) for visual and aural reception of 450-470 mc signals.

cavity from the antenna. Out of the cavity these signals are fed to the converter which amplifies and converts them to 28 to 48 mc. The signals are then fed to the 28 to 48 mc. tunable receiver. For example, if the receiver is tuned to 30 mc. a station operating at 452 mc. will be received. The Panadaptor is connected to the plate of the mixer tube in the tunable receiver. To convert the receiver IF of 5.25 mc. to the Panadaptor input frequency of 500 kc. a heterodyne oscillator of 4.75 mc. was necessary. A Heathkit LG-1 signal generator was used for this purpose.

Interference Prevention

Although it is not within the scope of this paper to go into ways of eliminating radio interference we would like to pass along some of the things we found helpful. These include the use of cavities, shielding, filtering and antenna separation.

Receiver Cavities

In areas where systems are located close together and intermodulation is very likely to exist, we found it helpful to use highly selective cavity resonators in the antenna feed line.

The cavity ahead of the receiver provides additional selectivity which reduces the possibility of intermodulation being produced in the receiver.

Transmitter Cavities

The cavity ahead of the transmitter reduces the effect of coupling between antennas by discriminating against signals radiating from one transmitting antenna to another. This reduces the possibility of intermodulation caused by mixing in the Class C final of the transmitter. Figure 8 shows a Western Electric UHF band pass antenna filter used with our Public Correspondence Receivers at the Field Building.

Shielding and Filtering

Where several cabinets housing transmitters are located close to each other, we found cabinet shielding and filtering was necessary to reduce

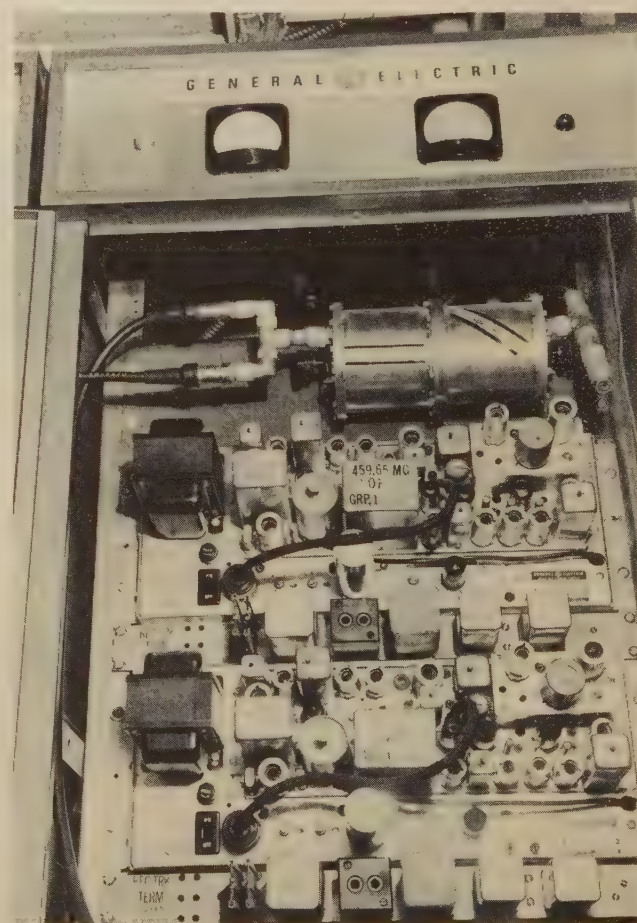


Fig. 8 - Western Electric uhf band-pass antenna filter used with uhf receivers.

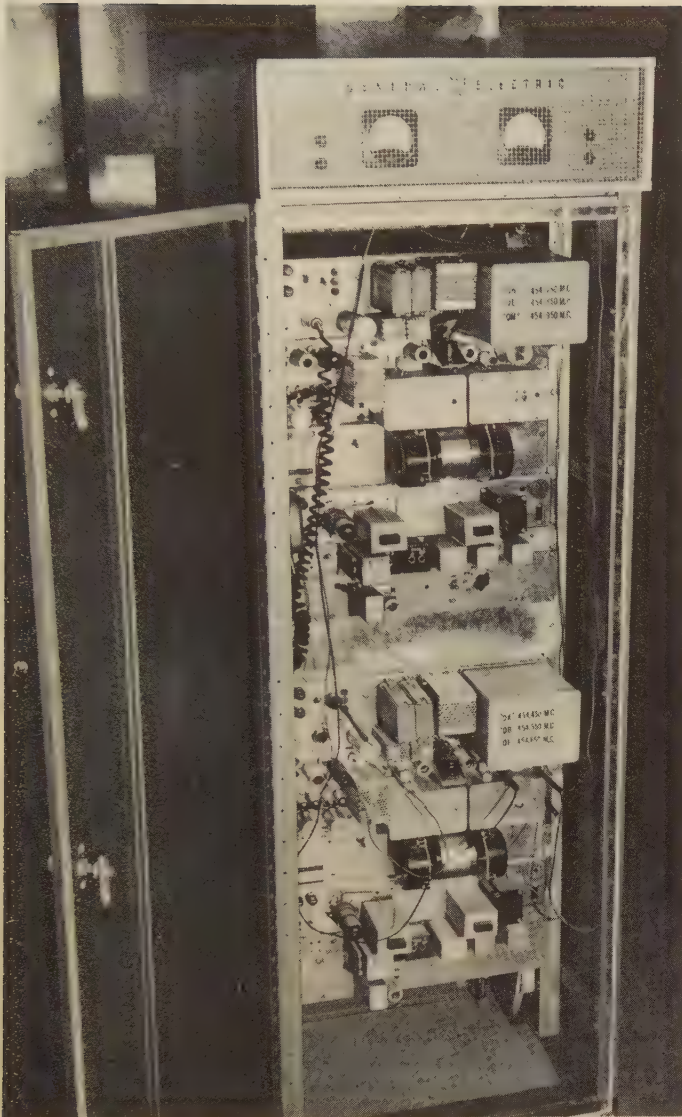


Fig. 9 - Shielded transmitter cabinet.

coupling between transmitters. Transmitters operating on adjacent channels were not placed in adjacent cabinets. The cabinets were made RF tight and all control and power lines entering the cabinets were run through filters. Figure 9 is a photograph of a transmitter cabinet to which has been added finger stock on the doors, additional door handles, and screen shielding of all louvers and meters. Although not shown in the picture a cavity is used in the antenna feed line and all power and control wiring is filtered.

Antenna Separation

Where several vertical gain antennas were located close together, they were mounted one above the other to take advantage of the reduced coupling. Where this was not possible and antennas had to be mounted parallel to each

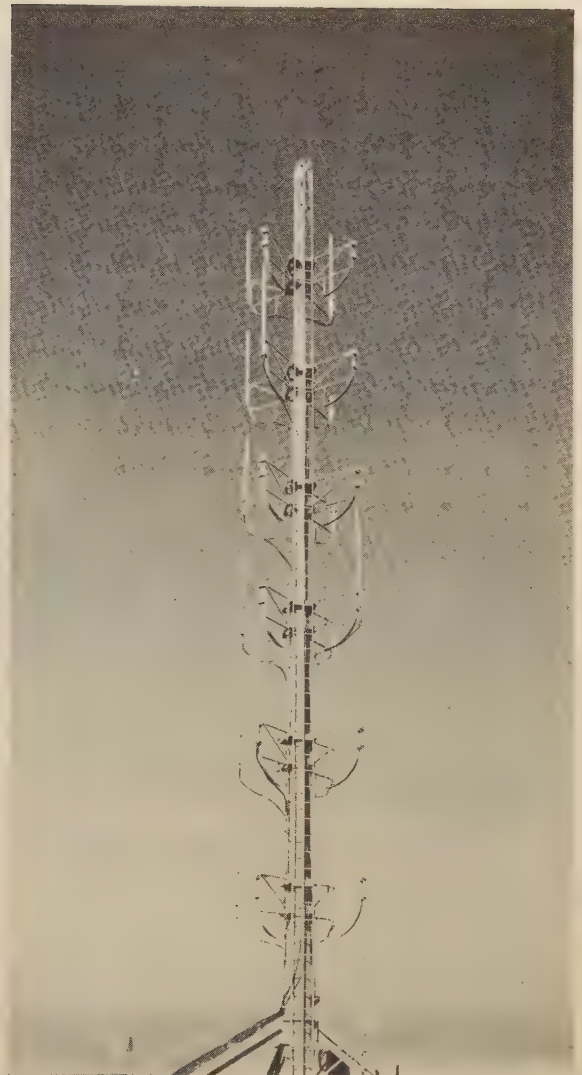


Fig. 10 - Mast with vertically stocked antennas.

other the frequencies of operation were selected carefully taking into account other systems operating in the same area.

Figure 10 is a photograph of our mast at the Field Building showing vertical stacking of antennas.

Conclusion

In conclusion, radio interference to UHF mobile system cannot always be prevented. When it exists knowing the source and cause will help in taking steps to eliminate it. If the source and cause cannot easily be identified, a tunable receiver covering the UHF mobile band with a panoramic attachment can be a real aid in identifying the sources.

TRANSMISSION TESTS ON A TRIAL SYSTEM OF TELEPHONE SERVICE FOR AIRCRAFT

R. V. Crawford
Bell Telephone Laboratories, Inc.
Murray Hill, New Jersey

Summary -- This paper gives results of transmission tests on the air-to-ground telephone system which is presently in operation at 450 mc on a trial basis with land base stations located at Chicago and near Detroit. Received carrier level measurements, using a chart recorder, were made at both land stations prior to the start of commercial service on September 15, 1957. The effects of base station antenna height, aircraft elevation and distance from base station, nulling, capture in the overlap zone and aircraft antenna patterns are discussed.

Introduction

Radio communication with aircraft is not new. Recently, however, there has been considerable interest in using this means of communication to provide a public telephone service to aircraft, with interconnection to the regular telephone network. To obtain practical experience with such a new service and to evaluate the many factors involved, two Bell System Operating Companies have undertaken a commercial trial. The trial system, which involves a ground base station here in Chicago and another at Dixboro, near Detroit, has been in operation since September 1957 with satisfactory results.

Time limitations prevent my giving you a complete description of the trial system; however, this was covered in a paper which Mr. L. M. Augustus of the Michigan Bell Telephone Company presented at the 1957 IRE-PGCS Aero-Symposium, and which is to be published as paper No. 58-1293 in the Transactions of the A.I.E.E. Briefly, the system is operated on one of the two-frequency channels normally assigned to the Domestic Public Land Mobile Service in the 450 mc range. Both base stations use the same frequencies, and the base transmitters and receivers are of FM types similar to those used in our mobile telephone service to land vehicles. Gain antennas with vertical polarization are employed at the base stations. I shall fill in some further details later, but now I should like to turn to the subject of transmission tests, the main topic of this paper.

Prior to placing the trial system into commercial operation, limited tests were made to check earlier estimates of coverage and to determine how RF propagation would be affected by various factors. These include:

- (1) Distance and altitude of the aircraft, also its orientation and attitude.
- (2) Different heights for the base station antenna.
- (3) Terrain conditions, especially land versus water.

- (4) RF signal "nulls" caused by multipath propagation.

Some observations were also made on the capture effects encountered by the aircraft when in the overlapping coverage areas of the two base stations. In addition, measurements were made to determine the efficacy of noise-cancelling microphones in reducing the effects of ambient acoustic noise in the aircraft.

Test Equipment and Sites

A brief outline of the test equipment will be essential to an understanding of the results. In the propagation tests, a continuous RF signal was sent from the aircraft in flight, and the signal received at the ground station was registered on a paper strip recorder. This recording setup is shown on Figure 1.

Such measurements were made at both Dixboro and Chicago, and these two stations were situated on sites which provided quite different antenna locations. At Dixboro, about 30 miles west of Detroit, the station was in relatively open country as shown in Figure 2. Two vertically polarized antennas, with rated gain of 6 db over a half-wave dipole, were mounted at heights of 35 and 50 feet. One or the other of these antennas was used for each test, though most of the results I shall discuss were obtained with the higher one. The cable connecting the antenna with the recording receiver had 0.8 db loss, so the "effective gain" may be figured as about 5 db.

At Chicago the station was in the Field building, located in the congested downtown area. A 7.5 db gain antenna was located at the top of a 74' mast on this building, as shown in Figure 3, giving a total elevation of about 600' above ground. Because of cable attenuation and other

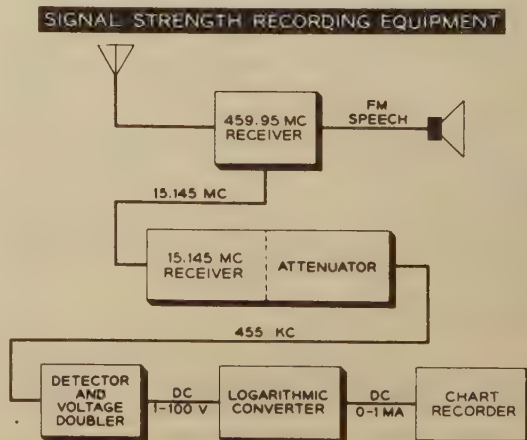


Fig. 1

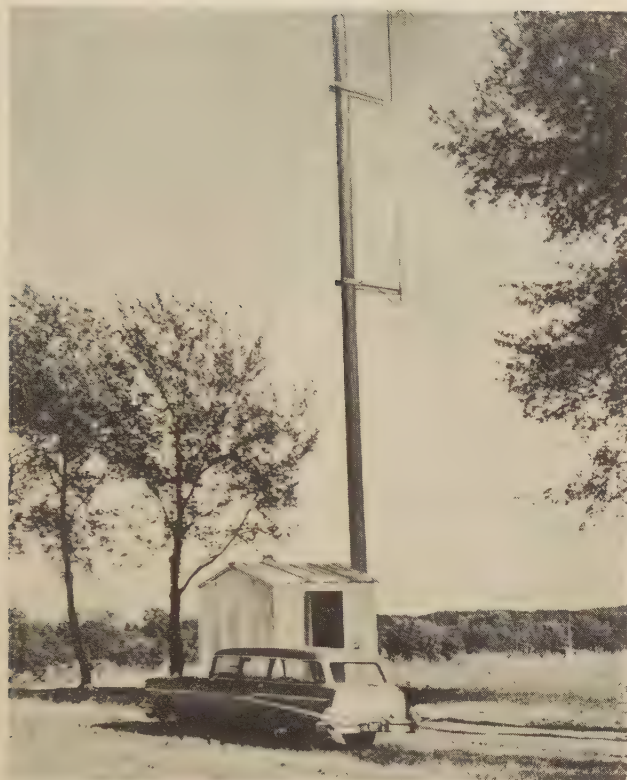


Fig. 2 - Measuring site at Dixboro.

losses caused by feeding several other receivers from this antenna, its net gain effective at the recording setup was reduced to about 0.5 db.

Two different types of aircraft (DC-3 and Navion) were involved in these studies. The DC-3's used for most of the tests were provided by Mr. A. J. Runft of the AC Spark Plug Division of General Motors. They were each equipped with an airborne receiver-transmitter of AC Spark Plug design, and the measured RF output of the transmitter during these tests was 15 to 18 watts. A

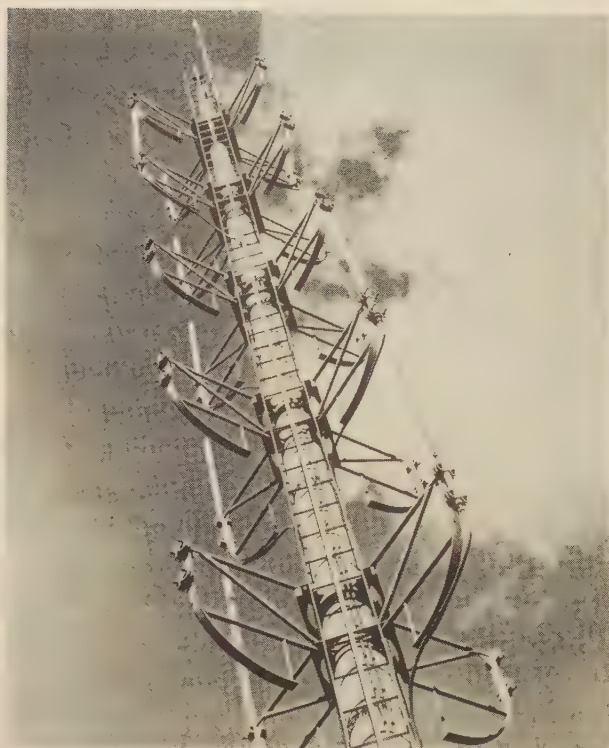


Fig. 3 - UHF antenna mast atop field building at Chicago.

specially designed whip antenna, enclosed in a fiberglass radome, was mounted under the fuselage along the center line of the aircraft. Figure 4 shows this antenna slightly to the rear of the twin pitot tubes.

Some tests at the Chicago station were made with a Navion aircraft operated by Mr. A. A. MacDonald of Motorola. This was equipped with a Motorola vehicular set adapted for airborne operation and having measured RF output of 12 to 14 watts. The antenna, as shown in Figure 5, was a



Fig. 4 - DC-3 aircraft.



Fig. 5 - Navion aircraft.

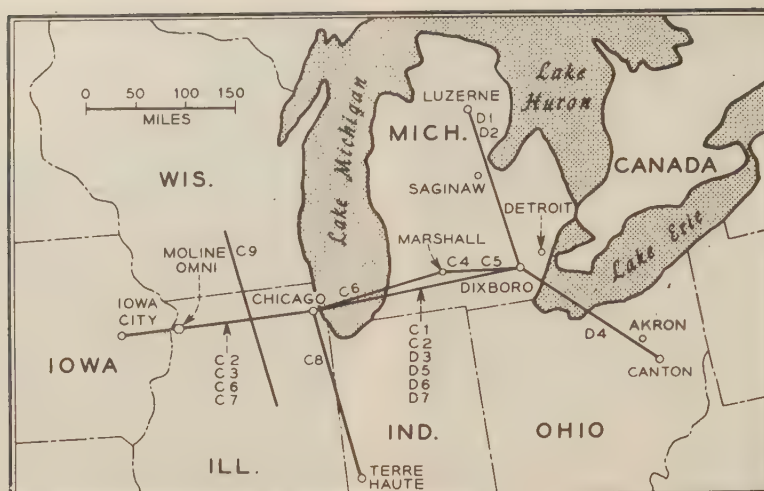


Fig. 6 - Aircraft courses.

vehicular quarter-wave whip mounted under the right wing and about 12 inches behind the right landing gear well.

Propagation Measurements

For the basic propagation measurements an RF carrier was radiated continuously from the aircraft, which was kept in level flight directly away from or toward the recording base station. Figure 6 shows the courses flown from both the Chicago and Dixboro stations, which are 205 miles apart. In general these test flights, at selected altitudes between 3200 and about 14,000 feet, were extended until the aircraft's signal dropped below the minimum usable level, arbitrarily chosen as 6 db above 1 microvolt.

In analyzing the results of these tests it was of course necessary to correct the recorded data in accordance with recorder calibrations, and also to condense the data considerably, since an original chart often ran to many yards of paper. The original charts, however, are of interest in showing the actual character of the received signal fluctuations. Figure 7 shows a copy of sections from the chart obtained at Chicago on a DC-3 flight at 9300 feet. The aircraft started near the eastern shore of Lake Michigan, passed westward over the lake and the Chicago station, and continued westward until the signal faded out. The chart sections shown cover the flight from about 60 miles east to 70 miles west of Chicago. One horizontal division represents 20 seconds of flight time. The received signal fluctuations indicate considerable "nulling" due to partial cancellation of direct and reflected rays. As would be expected from the path geometry these dips in the signal are most closely spaced when the path is short and more widely separated when the aircraft is farther from the station. On the over-water path east of Chicago the signal gyrations are deepest - some 10 to 15 db - while on the over-land section they are a few db less.

For comparison, Figure 8 shows a plot of the reduced data for the entire extent of the same

flight. Some of the fine detail has been lost, but all significant maxima and minima are indicated. Since the vertical scale is in received microvolts it can be seen that the signal did not fall below usable level until the aircraft was about 165 miles distant.

Figure 9 shows the results of a similar flight in the other direction, with the aircraft starting slightly west of Chicago and proceeding eastward until the signal was lost at about 180 miles. Here a few nulls dropped the signal below usable level, but in only two cases did they persist for as long as one mile of aircraft travel.

The next figure (Fig. 10) covers a flight at a lower elevation and with a different aircraft, but also based on the Chicago station. It shows a run with the Navion at 3400 feet. It will be noted that while the signal drops off more rapidly than in the higher-altitude tests, contact was

RECORDED SIGNAL STRENGTH AT CHICAGO DC-3 FLYING FROM EAST TO WEST

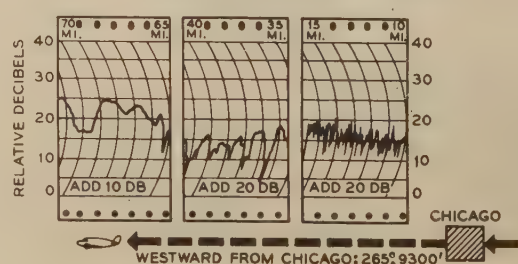
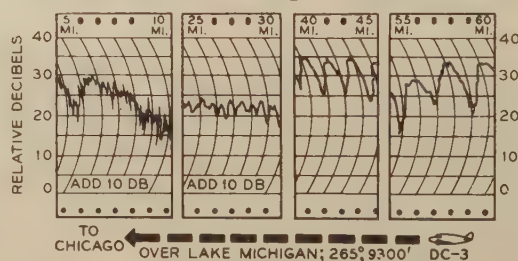


Fig. 7

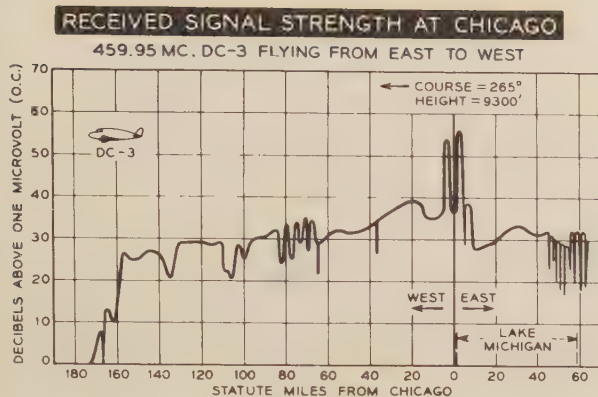


Fig. 8

continuous for over 120 miles to the west and 130 miles to the east.

Turning now to the tests at Dixboro, with its much lower ground antenna, Figure 11 shows the results of DC-3 flights at elevations of 3200 and 9100 feet. The aircraft started 10 miles east of the station and flew westward over it, continuing on-course to fade-out at 75 miles. The plane then climbed to 9100 feet to re-establish contact and then continued on-course until the signal was again lost at 125 miles. It will be noted that there was little evidence of nulling in this particular run, and also that the rate of signal decrease with distance was much more rapid than in the Chicago tests with the 600-foot base antenna.

Other tests of this kind were made, but this is enough of the details. The results are summarized on Fig. 12, which shows the coverage ranges obtained from both the Dixboro and Chicago stations at various aircraft elevations. Except for the two encircled points, these data are bracketed by two sets of straight lines, one pair for measurements on a 50-foot high antenna and one pair for the measurements on the 600-foot high antenna. The encircled data were obtained for the aircraft on the southeast course from Dixboro wherein the terrain gradually falls off in elevation and hence the 50-foot measuring antenna has a greater effective height for this direction. The data obtained for the 35-foot high antenna indicated the limit-

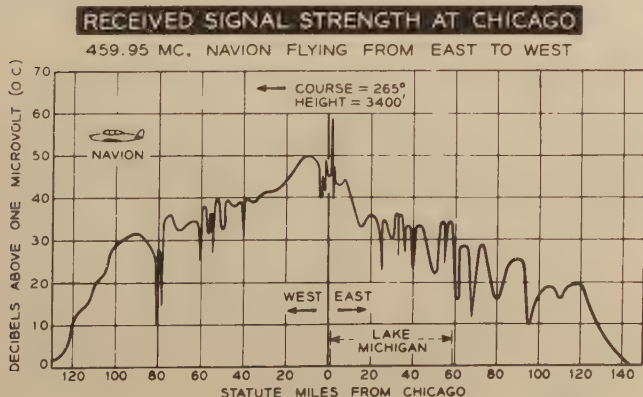


Fig. 10

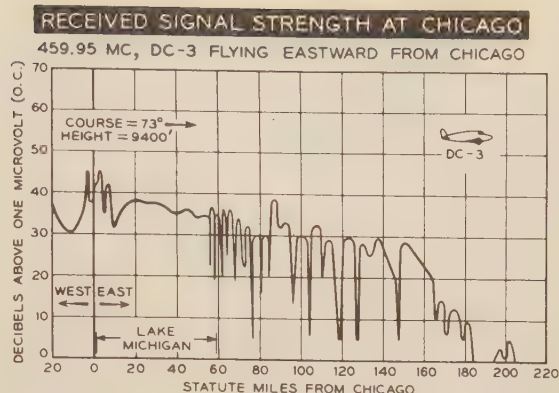


Fig. 9

ing coverage range to be reduced some 20 miles from that for the 50-foot antenna.

As a matter of interest, all four curves of Figure 12 have been extended to aircraft elevations of 14,000 feet. Since only one flight was made at this elevation, and the other flights at not over 9500 feet, this should be given due recognition in interpreting the curves.

It is of interest to note, in Figure 12 for the 600-foot antenna height, that the coverage range was some 10 to 15 per cent greater for the path where the aircraft route was over water for 60 miles adjacent to the measuring site.

A word of caution is in order concerning the ranges shown on Figure 12. These were determined in straightaway level flight; and as will be discussed later, for conservative engineering, some allowance must be made for added path losses, caused at times, by unfavorable attitudes and orientations of the aircraft.

Nulling Effects

As was shown by the recorded propagation data, a considerable number of nulls or signal dips occurred in some of the tests. As expected, tests made with the 35-foot ground antenna showed the least of this effect, and the 600-foot antenna the most. The nulling effect was not at all seri-

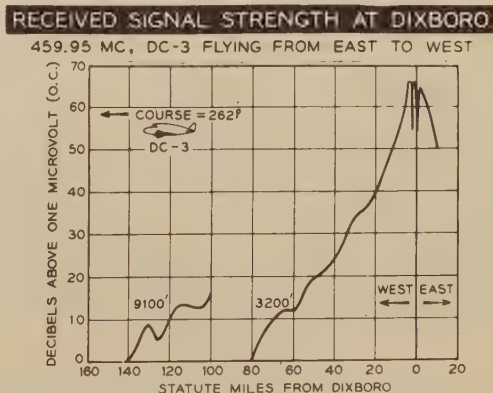


Fig. 11

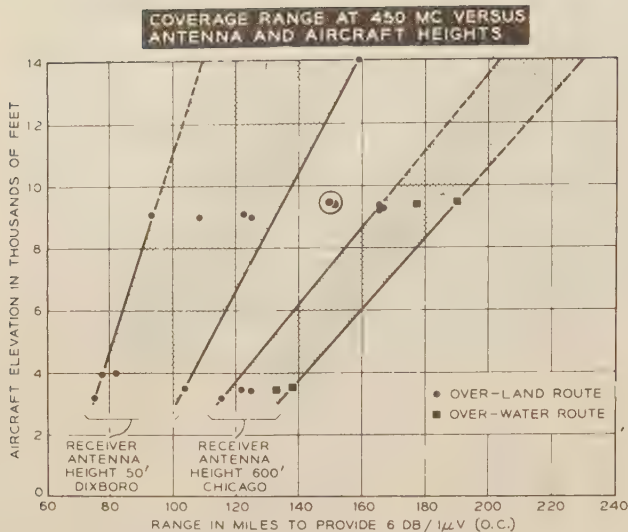


Fig. 12

ous at an antenna height of 50 feet. The over-water paths showed somewhat deeper and more regular signal gyrations than were observed over land. Also, the higher-altitude flights showed the most frequent and the deepest nulls. In general, the more pronounced nulls depressed the signal some 5 to 20 db below average value, over a distance of one to five miles of aircraft travel. In the final analysis however these nulls had little adverse effect on either limiting range or continuity of contact within this range. This resulted, from the fact that most of the nulls did not drop the signal below the minimum usable level, and the few that did were of short duration.

Aircraft Antenna Radiation Patterns

A number of tests were made to determine the horizontal plane radiation patterns of the aircraft antennas, with the aircraft in level flight and also at various attitudes up to a 30-degree bank. These patterns were obtained by measuring the received level of carrier from the aircraft while it made tight circles over a reference point far distant from the base station.

Only a few of these patterns can be shown. Figure 13 shows the pattern obtained from the DC-3 as it executed a flat turn, which the pilot thought quite improper for a well-managed plane. This figure therefore corresponds to the effect of various headings for the aircraft in level flight.

The pattern effects of a complete turn at 20° banking angle, for the same DC-3 aircraft, are shown in Figure 14. As indicated by the notations adjacent to the airplane outlined in the center of the pattern, the left wing was the low one during this maneuver. Here it will be noted that the effective carrier level is considerably reduced over a sector of approximately 90°, caused largely by the shadowing effect of the wing.

For comparison, Figure 15 shows the flat-turn pattern of the Navion aircraft. It will be recalled that the antenna here was mounted off-

center, and the effect of this offset shows up in the pattern.

Summarizing the results of these and other pattern measurements, and lumping the results for the two different aircraft, it is concluded that in level flight unfavorable orientations may drop the signal some 13 to 18 db below the level that would be found without the distortion effect of the aircraft structure. Unfavorable attitudes, during banked turns, may cause further losses over sectors exceeding 90° in width. For reasonable reliable communication under commercial flight conditions, however, it seems likely that an allowance of some 12 to 15 db will take care of most of these effects.

Capture Effect in the Overlap Zone

For aircraft flying at heights ordinarily used, the coverage zones of the Chicago and Dixboro base stations will overlap; and in this overlap zone some interference may occur if both base stations are simultaneously on the air. In commercial operation of the trial system, traffic operating procedures have been adapted to prevent such interference. During the tests however, some studies of these possible interference effects were made on a DC-3 flight from Chicago toward Dixboro at 9000 feet elevation. Different talkers transmitted simultaneously from the two base stations, and observations were made at the receiver in the plane.

Good clear, low-noise transmission was received from Chicago until the aircraft receiver was able to also receive a signal from Dixboro, at which time a slight amount of degradation resulted from the presence of a 2 kc audio tone caused by the heterodyning of the two carriers. As the plane continued farther into the overlap

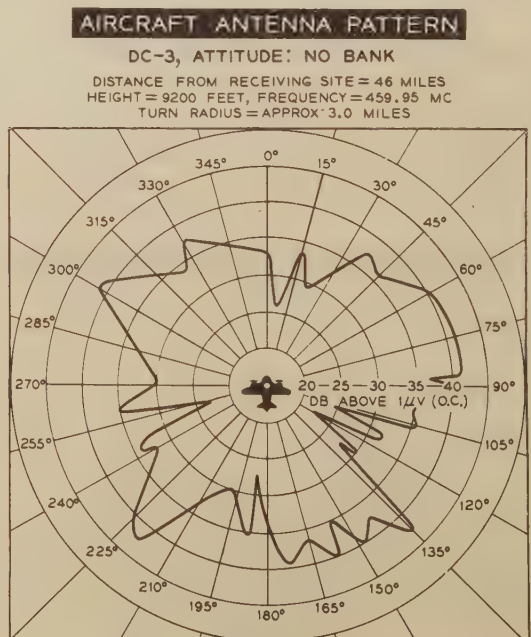


Fig. 13

AIRCRAFT ANTENNA PATTERN

DC-3, ATTITUDE: 20° BANK

DISTANCE FROM RECEIVING SITE = 46 MILES
HEIGHT = 9200 FEET, FREQUENCY = 459.95 MC
TURN RADIUS = APPROX 1.5 MILES

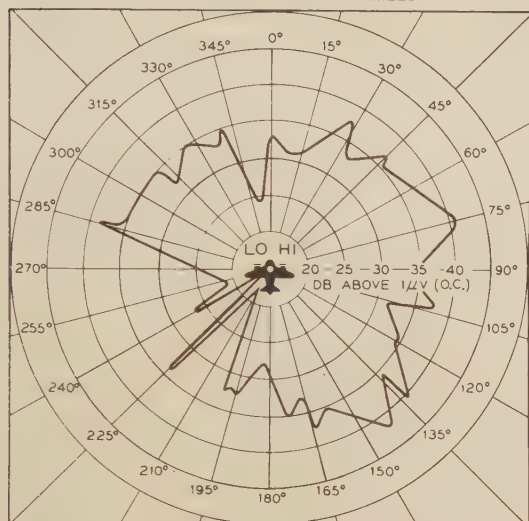


Fig. 14

zone toward Dixboro, there was a distance of 30 miles in which speech, received mainly from Chicago, was adversely affected by intervals of speech transmission from Dixboro. Communications could not be considered entirely reliable in this area if both transmitters were on simultaneously. As the plane continued further into the overlap zone toward Dixboro, the speech transmission from Dixboro became controlling with only the 2 kc audio heterodyne present until the aircraft receiver was beyond the influence of the Chicago transmitter. Beyond this point good clear transmission was again obtained.

To summarize the results of these observations - from a heterodyne standpoint, the extent of the overlap zone was found to be 70 miles at this aircraft elevation. From the standpoint of speech interference, however, the overlap zone covered only about 30 miles. For a short distance, some 5 to 10 miles, the speech from both base stations was unintelligible.

Microphone Effects

In transmissions from aircraft to ground the high ambient noise in the plane is picked up by the handset transmitter unit and degrades, to some extent, the speech-to-noise ratio at the listening end of the circuit. Some tests were made to determine the amount of improvement obtainable by using a noise-cancelling transmitter unit in the handset of the aircraft installation. In these tests speech was transmitted from the aircraft, using first a Western Electric Co. F1 transmitter unit and then a noise-cancelling unit. Speech-to-noise ratios on the transmissions received at the ground station were measured by various methods, using both flat and weighted measuring sets. It was found that the noise-cancelling unit gave 8 to

AIRCRAFT ANTENNA PATTERN

NAVION, ATTITUDE: NO BANK

DISTANCE FROM RECEIVING SITE = 135 MILES
HEIGHT = 7300 FEET, FREQUENCY = 459.95 MC
TURN RADIUS = APPROX 3.0 MILES

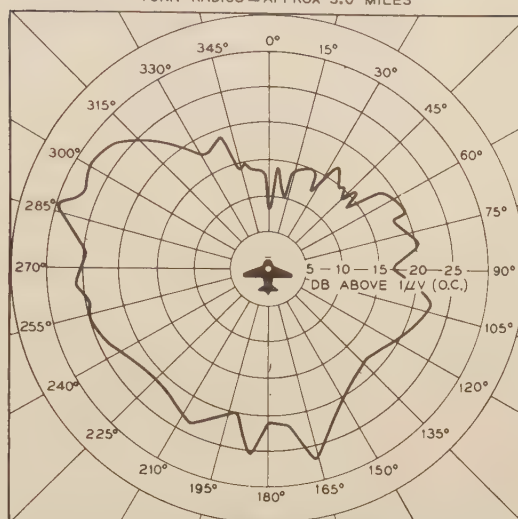


Fig. 15

12 db improvement in speech-to-noise ratio, which indicated that it is well worth using for this kind of service.

Quality of Transmission

Because of the relatively low level of man-made noise which prevails in the UHF band, good speech-to-noise ratios are obtained in this service as long as the received signal level is high enough to overcome receiver first-circuit noise. When the aircraft approaches the radio horizon, the received carrier level drops rather abruptly below usable level. As a consequence, there is very little "fringe-area" or marginal coverage. The net result of these factors is that excellent transmission can be obtained out to about the radio horizon which is essentially the limit of effective communication when using high elevated land station antennas. For lower land station antenna heights, the effective communication range will be slightly less.

Conclusion

In summary, it was concluded from the tests that the trial system was capable of very satisfactory performance, which has been borne out by the results of commercial operation. Nulling effects due to multipath propagation were found not to be seriously troublesome. Overlap interference, while its effects can be minimized by proper operating procedures, remains a problem which will demand further attention.

Acknowledgement

The writer wishes to acknowledge the assistance of many who co-operated in these tests.

Without their cooperation and untiring efforts, these tests would not have been possible. Among those participating were Messrs. J. D. Malone and A. J. Runft of the AC Spark Plug Division of General Motors Corporation; A. A. MacDonald of Motorola, Incorporated; L. M. Augustus and R. J. Piper of the Michigan Bell Telephone Company; R. Bez, L. D. Brewer, K. V. Glentzer, C. B. Hopper and R. J. Klein of the Illinois Bell Telephone

Company; M. C. Fruehauf of the American Telephone and Telegraph Company and H. J. Bergmann of the Bell Laboratories who assisted in all of the tests. Thanks are due also to the several pilots of the General Motors Air Transport Section and especially to Tom Milton of that organization who volunteered to act as co-pilot on all of their flights to provide the continuity of procedure so much needed in tests of this kind.

SHADOWS OF THE FUTURE IN VEHICULAR COMMUNICATION

David C. Pinkerton
General Electric Company
Syracuse, New York

Summary

This paper constitutes a discussion of certain changes in vehicular communication services and equipment that may be expected in the not too remote future. These changes are related, not only to technology, but also to the problems created by the slow but sure depletion of the available radio frequency spectrum space.

Attention is directed to the great potential that exists for better utilization of the spectrum through improvements in the space (or volume) and time dimensions. It is pointed out that the effective use of air time through automation of routine or repetitive type communications promises to give, in effect, a many-fold increase in the available spectrum.

Introduction

Vehicular and personal communication is still in a state of vigorous growth. The growth potential is tremendous--and during this growth there will be great changes that might be compared to the change in an adolescent child in developing into a full grown adult. It is the intent of this paper to look into the relatively near future of vehicular communication. Hazy blue sky dreaming is carefully avoided as attention is devoted to the changes that are on the horizon today in order to give proper orientation to our day-to-day planning.

Although the blue sky approach is avoided here, such speculation is not entirely out of order. Ten years ago, I am sure, there were few of us who could visualize the great impact that the invention of the transistor would have on our business.

The solid state revolution in electronic components has meant much in the field of vehicular radio in terms of decreased size, lighter weight, greater efficiency, and ultimately, we hope, lower cost of equipment. This revolution, together with the development of micro-miniaturization techniques of fabrication, has not only given great impetus to the development of improved vehicular and portable equipment but is rapidly opening up the new field of personal communication.

Personal Communication Devices and Services

A variety of personal communication services are being developed, which can be grouped into these categories: paging, selective signaling, and two-way communication. The basic purpose of personal paging and personal selective signaling services is to improve the overall efficiency of a wide variety of organizational functions by making certain that communication can reach all personnel at any time.

Personal paging is a service that has seen expanded application the past couple of years. By definition this service uses voice calling and the subscriber has to listen to his receiver constantly or occasionally to find out if a message for him is being repeated at regular intervals. This type of paging has provided useful service, but it constitutes an uneconomical use of the air time and of the subscriber's time. As a result the number of subscribers that can be served is limited. Consequently, selective signaling methods have been devised that are capable of signaling a single desired subscriber out of 10,000 or more by sounding an annunciator in that individual's pocket. To find out why he is being signaled the subscriber then calls a prescribed station by other communication means.

Just to highlight the technical progress that has been made in electronics in recent years, attention may be drawn to the development of a micro-miniature 10,000 call selective signaling device. Just a few years ago the task of providing such a device in a space the size of a cigarette package seemed very difficult. Today we find it possible to do this in half the space originally allocated, using multiple tones and resonant reed frequency sensitive relays. In addition, an alternate means has been developed for providing selective signaling with a 100,000 call or greater capacity in this extremely small size. This high capacity signaling system employs a binary digital code. It will be described briefly later.

The personal voice communication receiver also is proving to be very useful to the emergency services. The guard or patrolman who works afoot or on horseback can now be kept in touch with headquarters

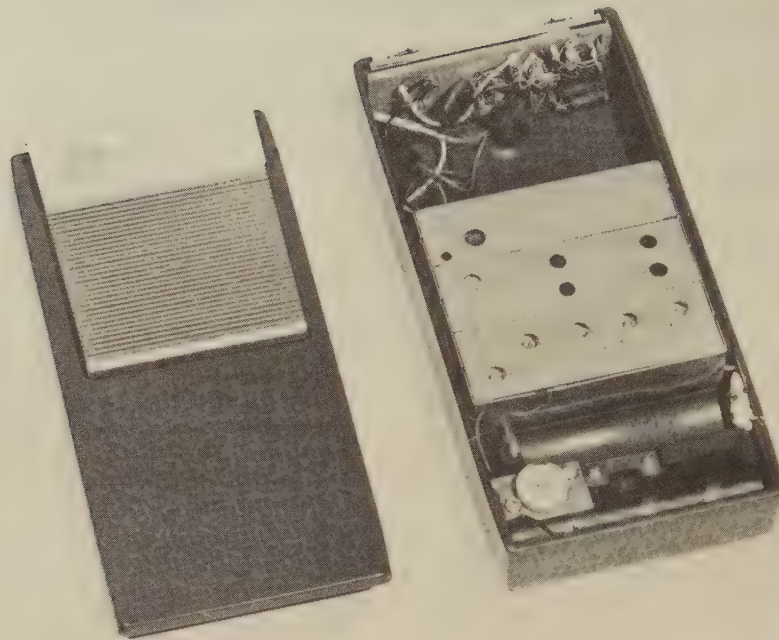


Fig. 1 - Transistor pocket vhf communication receiver.

and his effectiveness is thus greatly increased. To be sure, pack sets and hand carried sets have been employed for this type of service for some time, but the order of magnitude of reduction in size and weight brought about by the pocket receiver promises to so improve this service that it is expected to expand rapidly.

Pocket two-way communication is on the horizon. It is here today if your pockets are large enough. (Size of pocket--not pocketbook.) Today's transmitters, that are of professional calibre all use some tubes in order to provide the required power in the frequency bands allocated for mobile services. The reason for this is that transistors having sufficient power at these high frequencies are not commercially available today. Low power, all transistor transmitters may be available soon and these will give a limited service that may be useful to some, but for most applications a power of one watt or more is highly desirable.

This year has seen the announcement of new, all transistor pocket receivers of greatly improved design. The first slide shows one of these receivers announced in 1958. A few of the performance characteristics of this receiver are as follows:

Frequency bands:	25-50 mc. and 150-174 mc.
Sensitivity:	1.5 microvolts for 12 db SINAD ratio

Selectivity:	+6 kc, -6db and +60 kc, -70 db (EIA Method)
Spurious responses:	-60 db except one -45 db.
Battery:	6.5 volt mercury cell
Current drain:	5.0 ma.
Number of transistors:	12
Dimensions:	2.755"X.905"X6.0"
Squelch Operation:	Continuous

As can be seen from the above specifications this receiver is a professional piece of equipment, designed to perform a real service--reliably, and fully. These specifications are comparable to those of good mobile receivers. The receiver is a double superhetrodyne using crystal control for both oscillators.

The slide also shows the inside of the personal receiver as equipped for audio output. This receiver may be equipped for selective signaling, in which case the squelch and audio output circuits are replaced with the selective signaling and alarm circuits. Extra room has been allowed for the resonant reed relays. In the picture the self contained ferrite antenna is shown at the bottom. This type of antenna provides the best performance possible for this application. Above the antenna is the single 6.5 volt mercury battery. Above the battery is the receiver proper, with squelch and audio circuits and controls at the top. Ample room is allowed

for the addition of selective signalling. Construction here provides considerable accessibility and great ease of adjustment.

This is the present in personal radio communication. What does the future hold in this area? Smaller size and longer battery life are rather obvious trends. The shadows of the future are relatively clear and distinct here.

New components that promise appreciable size reduction include: barium titanate and crystal filters for i-f applications, and smaller transistors. The second slide shows an experimental doped barium titanate i-f filter having a high order of selectivity at 290 kc. This filter can easily be reduced in size and given a more favorable form factor.

Longer battery life is very important in personal communication. Great strides have been made in improved batteries² but the development of circuits and devices having very low current drain have had an even greater effect on improved performance in this regard. The tetrode transistor has been found particularly valuable in the head end of pocket receivers because of its ability to perform well at low currents. The future promises great improvements in battery life and/or reduction in battery size..

Equipment improvements are only a part of the future in pocket communications. Great improvements in the utilization of these new products, within the whole of the communication system, are

in store, primarily in the area of two-way personal communication. Means by which a person can leave his vehicle on foot with his pocket set on his person, and still maintain satisfactory communication with home base by repeating via the vehicular station can be devised. Other means by which better communication from base station to mobile (or personal) can be provided, with very low power mobile stations, may eliminate the need for a mobile repeater in many applications.

Providing Room for Expansion of Service

Many of you may be wondering whether this greatly expanded use of the allocated frequency spectrum by mobile and person will soon be the limiting factor in the expansion of vehicular communication. Many of us believe today that the growth of the vehicular communication services is being stunted by lack of spectrum space. It is probably very true that the mobile services have far greater needs in this regard than many others, and already have done a sacrificial service to the radio industry in making the most of their allocations.³ Channels have been split, selectivities have been increased, and the modulation index has been decreased to decrease the width of the transmitted spectrum. Great improvements have been made in the past decade in the reduction of spurious radiation.⁴

In EIA's recent comments on FCC Docket 11997, a basic philosophy was described for the evaluation of frequency spectrum utilization by a three dimensional method. These three dimensions are: frequency, space (or volume), and



Fig. 2 - Developmental ceramic IF filter (290 kc).

time. Most of the emphasis to date has been placed on the frequency dimension. Great opportunities, however, exist in the better utilization of the space and time dimensions.

Space Dimension Utilization

The growing recognition of the opportunities that exist indicates that the future will find much improved utilization of the space and time dimensions of radio communication. In this respect one important improvement in the use of the space dimension has already been announced. With Automatic Power Control it is now possible to limit station radiated power to a lower level as required to continue communication with a given mobile station. Automatic power control may be defined as a system that automatically adjusts the power output of a base station transmitter inversely in proportion to the signal received from a mobile station. It is a system that controls the base station power to a level just sufficient to provide reliable communication to the designated mobile station. This is a very important step toward compliance with the FCC regulation which states "The power which may be used by a station in these services shall be no more than the minimum required for satisfactory technical operation commensurate with the size of the area to be serviced and local conditions which affect radio transmission and reception." Tests have been highly successful; only a small amount of additional equipment is required at the station; and reliability of communication is unimpaired. Benefits include reduced interference to other services through better sharing of channels, possibly obtaining permission for the use of higher peak power, or some of each of these benefits.

The application of automatic power control clearly does not bring direct benefits to a single user immediately upon installation. However, it is felt that this fact will not deter its application greatly as it comes in the same category as channel splitting, modulation limiting, and transmitter audio filtering. They are beneficial to all when all systems conform to common technical standards. The history of the past several years has demonstrated that most users of vehicular communication equipment are ready and willing to improve their systems for the common good.

A second means of obtaining improved utilization of the space dimension that can bring direct and immediate benefit to the user is to use directional antennas, probably because of cost, complexity, and time lost in rotating the

antenna to the direction to be used for the desired communication. Right-of-way mobile systems find the greatest use of directional antennas.

To achieve the ultimate in performance, development is necessary that will result in an antenna that can be rotated instantly (electronic rotation) and automatically to the predetermined direction or to the direction of the calling mobile station. Not only would this type of operation result in reduced interference, but the effectiveness of the station transmitter power and receiver sensitivity could be greatly improved in the fringe area. With certain operating techniques it is possible to increase the effective range of the whole system.

A third means of improving the utilization of the space dimension is through the use of satellite stations. Satellite receiving stations (not space satellites) located advantageously throughout the area of operation, and connected to the central station by land lines or point-to-point radio can materially increase the operating range from low power mobile or personal transmitters.

Satellite two-way stations are an effective means of improving the space utilization of the frequency spectrum as the area of coverage can be made very great with low power transmitters throughout. In all such application it is, of course, desirable to compare the alternate means of accomplishing the communication desired by the user. Thus, systems engineering is becoming of increasing importance in vehicular radio communication work.

Time Dimension Utilization

The utilization of the time dimension has received some attention for a long time, but additional strides of great magnitude are possible today. This aspect of spectrum utilization is very frequently overlooked completely in discussions of spectrum crowding, and yet it is the most fertile field for improvement by a few orders of magnitude. This fact can be verified by studies in information theory.

Improved utilization of the time dimension of the radio communication frequency spectrum, like automatic power control, may not bring immediate benefits to the user in many cases. There are, however, other incentives to improved time utilization of radio space. The greatest pressure comes upon the user who finds that his communication system fails at times to keep up with the traffic required by his business or op-

eration. There are also incentives in terms of labor saving in that each minute wasted by personnel in accomplishing the necessary communication may be a minute taken from the performance of other responsibilities. In some of the larger systems, improved time utilization may also mean more effective use of the services of personnel using the communication system. Ultimately, the dark shadow of the depletion of the frequency spectrum resource will force the sharing of channels and improvements in time utilization will become imperative when the shared channel fails to be able to handle the traffic of all the sharing users.

It would be highly improper to create the impression that opportunities in this direction have generally been overlooked in applying currently available equipment. The proper picture of the available opportunities shows instead that rather radical changes in equipment and systems will be necessary.

The opportunities that have been taken advantage of have come rather naturally. The language and procedures adopted by the mobile services have made possible appreciable reduction in air time through reduction or redundancy and in reduction of errors of communications. This may seem to be a simple thing but its nature and importance should be recognized. Personnel, properly trained in the use of their radio communication system, can easily reduce air time to less than half that needed by untrained personnel.

Great additional improvement can be made through recognition of the routine nature of a large portion of the communication procedure. With elementary voice communication the simple procedure of establishing the contact by saying the name of the called party or the designation of the called station and having that person reply can take several seconds. Recent developments now make it possible to accomplish this in less than a second without the called person having to lift a finger. Selective signaling systems can be implemented that will instantly indicate that the two-way contact has been established with the designated vehicle. It is also possible to have such a system indicate whether the operator of the vehicle is attentive to the receipt of the message that is to follow. Furthermore, following the indication that the contact has been established it is possible for the base station operator to give the message, and for the mobile operator to indicate understanding by momentarily pressing a button. The only work the

mobile operator does in the entire communication is to momentarily depress a button. The added equipment required to accomplish these functions can be of little complexity and small size.

Perhaps the above discussion is not as clear as it might be. Certainly it has not yet been made clear at all just what types of recent developments have made these improvements possible, and how they may be applied to the reduction of the time utilization of the channel. Possibly, description of a recent accomplishment in selective signaling may serve to provide some clarification.

The basic selective signaling problem that was initially posed was to signal one out of 100,000 air mobile stations in less than two seconds of time, with great reliability, and using an airborne signaling decoder of very small size. The particular solution chosen involved the application of circuit techniques developed for digital computers. The selective code utilized was a 17 bit binary code having more than 130,000 combinations. This is the most efficient code possible for this function. The airborne decoder consists of transistor and memory core circuits of the type very commonly found in digital computers. The heart of the airborne device is a magnetic core shift register that has winding connections that correspond to the designated code of the aircraft. The third slide is a photograph of a "breadboard" airborne digital decoder (including power supply and subcarrier receiver for use on SSB channels). The fourth slide shows the same unit with the shift register panel pulled out for better view. This particular unit was designed for demonstration and test purpose and no attempt was made to attain small size. Reliability, by actual tests on a previous development model, showed 99.99% reliability against false calls at unity signal-to-noise ratio on the channel. This is equivalent to two false calls in 100,000 at zero db signal-to-noise ratio.

This type of signaling system is very flexible of application, as it can easily be designed to respond to any of three codes representing individual call, group call, and call-all with an insignificant increase in size. Likewise the code to which the device responds can be readily changed to any of the 100,000 plus combinations in a few seconds without changing any parts. The device has no moving parts except the power switch and a push button to turn off the flashing light which indicates receipt of a call. The device has no relays.

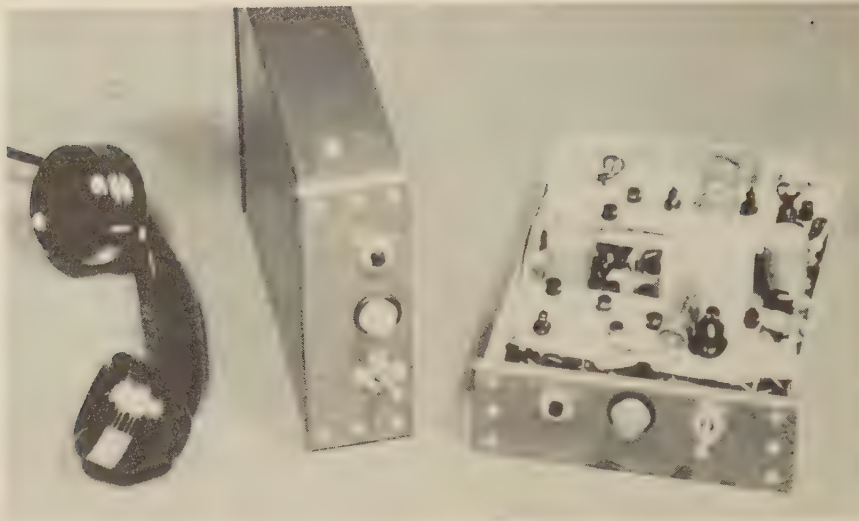


Fig. 3 - Airborne digital decoder for high capacity selective signaling.

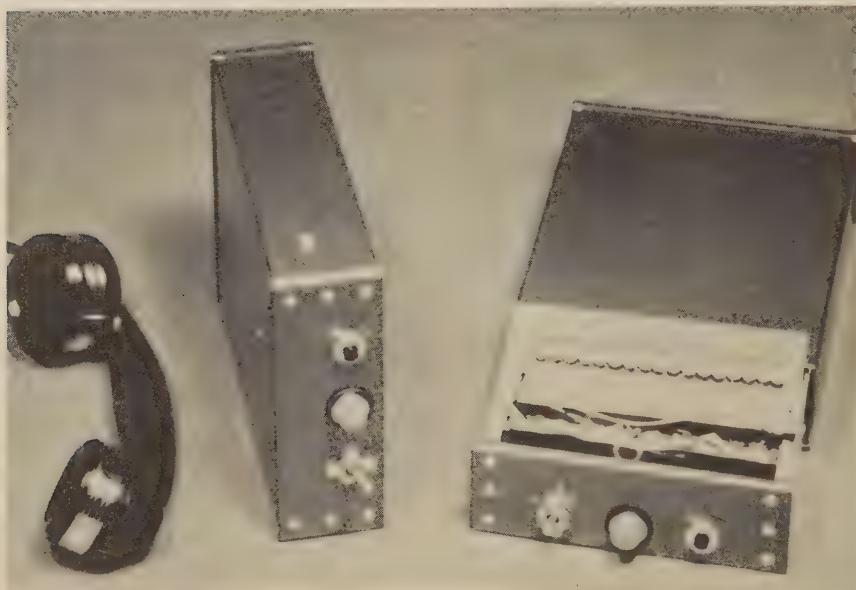


Fig. 4 - Airborne digital decoder for high capacity selective signaling, showing the shift register.

The output of this digital decoder can be used to perform any of a number of functions such as: sounding an annunciator, opening the squelch of a receiver, closing the circuit to a teletypewriter, or initiating an automatic operation or sequence of operations. With added circuitry of a similar nature it could be used to automatically initiate a code transmission back to the calling station indicating that contact had been established. Such a function would serve to increase the reliability of signaling to a figure that would differ from 100% by an insignificant amount.

Additional advantages of such digital coding of routine messages is that

they have an element of security and can be received reliably at ranges greater than have been found satisfactory for reliable voice communication.

The Dispatcher's Problem

Let us, for a moment, examine the problem of the dispatcher or base station operator of a large system of mobile radio equipment. This operator must have knowledge of: which units are in service, their location, destination or mission, the name or other designation of the operator and perhaps several other items of information. Locations are constantly changing; operators are going on and off duty; missions are being initiated. All of these things, and many

more are the subject of the information transmitted via the communication system. If one wants to one can regard the information transmitted as being the changes in this great amount of information that is stored in the records at the base station.

The ability of the dispatcher to store, modify, and recall this information is a measure of the effectiveness of the operation. The application of modern business machine aids to this function promises great savings, and the integration of the radio communication sub-system into the overall information processing system is a very natural step in today's progress.

Of course, there are many communication systems having so few mobile units that the dispatcher's function is not difficult and for which this type of consideration does not appear appropriate at the present time. On the other hand, there are many systems that have a very large number of mobile units and for which the dispatcher's problem in information handling and storage is very difficult. Such systems include state police, police for large municipalities, large taxi systems, toll roads, etc.

Suppose we let the imagination run for a moment in order to illustrate this point. The example selected here envisions a taxi dispatching system because it has factors that all of us should be able to picture readily. To orient your thinking I would like to ask each of you to visualize how these general ideas might be applied to the type of communication system with which you might be most familiar.

Envision the dispatcher of a taxi system seated before a small desk type information processing device that is dignified by the name of digital computer. By interrogating this device the operator can readily obtain the answers to such questions as:

How many vehicles are in service at this moment?

How many of these are idle, waiting for instructions?

How many can be expected to be idle in area Z?--in area W?

What is the location of vehicle Y?

Is vehicle Y vacant or occupied?

In short the operator no longer need remember a large amount of confusing information. In fact, it appears rea-

sonable to conclude that with such an aid one operator could do the work of two, and do it more effectively in that his final records are ready for processing for business purposes. Such business purposes include payroll and other personnel records, and billing and other accounting functions.

By now you are probably wondering what this has to do with the time utilization of the communication channel. One point is clear. If the basic working information of the system can be stored in this fashion, in a device using binary pulse codes, then this information can be transmitted using such codes. It should not be difficult at this point to visualize that a taxi driver, upon completion of an assignment will lower the flag on the fare meter and by this single act initiate the transmission of binary information that will modify the contents of the memory of the computer at headquarters to indicate that this vehicle is now available, its location is approximately north 3 miles, east 2.7 miles, and the amount of the fare just received was \$1.75. I'll not elaborate on the means of locating the vehicle's position at this time, now on the details of implementing this function as such cannot be done without revealing company proprietary information. Please note, that in this last example the station operator takes no part at all in the communication. His time is entirely free for other considerations.

With regard to the information handled I'm sure you will all be quick to recognize that there is much that the operator will not need to have readily available for instant recall, and information also is not easily subject to automatic handling. Examples include details of specific assignments such as customer's name, address, and the service or function to be performed on this assignment. This type of information generally is subject to written record not only for memory purposes until the assignment is completed, but also for business purposes. There often will be business record need or legal record requirements for this data and a typed copy must be made. Would it not be desirable in many instances to have this same typing function transmit a printed record to the vehicle assigned to perform the desired service? A simple, rugged teletypewriter for mobile service would be a great contribution to mobile communication. Recent developments indicate that such a device may not be long in coming.

Teletype communication from base to mobile will mean not only that the mobile operator can receive messages

without any effort on his part, but that the message is recorded automatically so that he need not make notes. In addition, if the operator is temporarily away from the vehicle, a message can be left for him. With teletype, selective communication is automatic. It is also compatible with other means of handling data by binary codes.

Better use of the spectrum is also realized not only in the time dimension through improved methods, but also in the frequency dimension, as a teletype channel requires only a fraction of the bandwidth required for voice messages.

Summary and Conclusions

Vehicular communication is in a stage of vigorous growth and development. Technical improvements in equipment are a major factor in the stimulation of this growth through reduction in size, improvement of reliability, reduction in power drain, and improvements in many performance characteristics. One major field recently made practical by these improvements is that of personal communication. The near future promises exceptional growth in the use of personal communication devices.

The future is expected to show a continuation of the present rapid pace of technical progress. Probably this pace will even be accelerated.

One factor that threatens to eventually limit the expansion of vehicular

communication is the depletion of the frequency spectrum (often referred to as a natural resource). The utilization of this spectrum space can be thought of as having three dimensions: frequency bandwidth, space utilization, and time utilization. The future is expected to see much greater emphasis on the improvement of space and time utilization.

Improvements in space utilization may be derived from:

- (a) Automatic Power Control
- (b) Electronically Rotating Directional Antennas
- (c) Satellite Station Operation (not space satellites)

Improvements in time utilization can result from the automation of the handling of appropriate portions of the information being communicated. This will require much technical development and great attention to the better integration of the communication sub-system into the overall business operation of the user. Greater utilization of business machine aids at the dispatcher's office is predicted. Ultimately limited access to the information storage of these machines may be extended to the operator of the vehicle in some types of service.

Eventually, it is predicted that many vehicles will be equipped with a teletypewriter, but it also seems quite evident that much need for voice communication will always exist as we know it today.

A NEW ERA IN COMMUNICATIONS THROUGH TRANSISTORS

William J. Weisz
Communications and Industrial Electronics Division
Motorola Inc.
Chicago, Illinois

Only 10 short years ago, the transistor was born. Even though it is just in its early childhood, it has already started an electronic revolution --- and the best is yet to come. The transistor is a tool that gives the circuit and equipment designer hitherto undreamed-of potential. I'm going to talk, today, about the transistor and its application to the two-way communications field.

The transistor was born as a point contact device, one which would give amplification of power by a solid device in an extremely small package without the necessity for a heated filament and high voltages. Then came the junction transistor, followed by the diffused base transistor, and other improvements and variations. (Figure 1.) However, the basic theory remained the same.

The transistor contributes to equipment tremendously in the following areas:

1. Small size
2. Light weight
3. Low power consumption, and by far the most important
4. Extreme reliability

Along with these advantages, there have been two big disadvantages, these primarily being the inability to operate at high ambient temperatures and high frequencies, not to mention their relatively high cost. Therefore, the introduction of transistors into equipment had to be done with these two limitations in mind.

The answers to some of the problems which have confronted us, and which have limited our application of transistors have now been found. The major problem solved is the limited UHF amplification capabilities of former transistor designs. The most recent advance in this area is the "Mesa Transistor", manufactured by the Phoenix Semi-Conductor Division of Motorola.

The term, "Mesa" is derived from the plateau-like structure which characterizes the physical configuration. The design of this transistor makes possible the micro-dimensioning control which is necessary for reproducible UHF performance. (Figure 2.) The design also establishes a thin, highly doped base region which is comparatively invulnerable to temperature extending somewhat above 100°C. No indium is used in the construction of the unit. Since it is baked out at 300°C, it is clean and free from organic contamination, which is responsible for a high percentage of the aging failures experienced with conventional designs. This is truly a tiny unit. The transistor we are making is approxi-

mately 25,000's of an inch square, with one aluminum strip and one gold strip on the Mesa measuring one-thousandth of an inch by six-thousandths of an inch. In other words, the length of the strip is only a little more than the diameter of a hair, and the strips are separated by about one-half of a thousandth of an inch. These strips, one of aluminum and one of gold, are laid down nearly one-hundred pairs at a time on a germanium slab by evaporating the metal through a mask. The really difficult problem in manufacturing is the one of welding a gold wire to each of these strips. Somewhat facetiously I might say that the maker takes a gold wire that he can't see and welds it on a strip that apparently isn't there! I personally found that I was totally unable to see either the metal strips or the wire with a naked eye. Mechanical engineer inventors have devised a truly remarkable micromanipulator to enable the welding of a gold wire on one of those strips in approximately fifteen seconds.

Now, as to performance, pilot production units will provide gains of about 12 db. to 15 db. at 160 mc., and about 20 db. at 70 mc. This is germanium, not silicon, and germanium is to be preferred over silicon for UHF transistors because germanium is almost three-to-one better than silicon in the matter of the mobility of the holes or the charges. This means that for a given design, germanium will operate at about three times the frequency that can be achieved with the silicon unit.

In this transistor design, one of the metal strips is the emitter and the other one is the base connection, and the distance between the emitter and the base can be controlled to micro-inches in the process of laying down the strips. This is a precise, controllable parameter which can be handled in normal manufacturing processes, and therefore, uniformity of performance and quality can be assured. Furthermore, it is possible to extend this design to make high-power, high frequency units, high-speed switching transistors and high-speed diodes. I believe that I am safe in predicting that this basic Mesa design will dominate the high frequency transistor art over at least the next five years, and probably for the next decade. This is truly a remarkable device, and the only real problems are related to the development of techniques to handle the micro-dimensions. I feel certain that techniques will be developed which will permit the manufacture of the unit at low cost ultimately.

Now, I said this was a small-size unit, and the next slide will give you some idea of the size. (Figure 3.) The reference object on the

right is a thin dime, and I can assure you that while this transistor case is small, there is far more empty space in that little can than there is transistor. While the first units we are manufacturing will operate up to a few hundred megacycles, it is within the realm of practicability to design units which will provide amplification at an upper level of about 10,000 megacycles.

Today, I would like to introduce to you two new products that have been made possible by the transistor, products that allow complete new methods of operation, heretofore impossible.

The first of these I am wearing right now. That's right, underneath my coat, I am wearing a complete two-way communications system. Here you see the Motorola HANDIE-TALKIE Pocket Receiver and the HANDIE-TALKIE Pocket Transmitter. Notice that the units are individually complete within themselves and I am wearing them on my belt. (Figure 4.) This slide shows a typical use of the equipment in an industrial situation. An accessory leather belt and leather carrying cases are also available where it is desired to wear the units as a complete single package that can be put on by just buckling the belt. (Figure 5.)

(Figure 6.) Here, now, is a real communication tool for the individual whether he be policeman, fireman or maintenance man, where he can be in constant touch with any other persons equipped with these units or any two-way radio.

In addition to its usage as a two-way package, the receiver can be used as a separate receiver only and carried by key men throughout the city. The HANDIE-TALKIE Pocket Receiver assures their being within constant touch of the base station.

The receiver has 17 transistors and 5 diodes. It has a chassis sensitivity of less than .5 uv. in the 25-54 Mc. band and less than 1.0 uv. in the 150-174 Mc. band. Of course, this full sensitivity is degraded somewhat due to the built-in antenna. It has audio power output of over 100 mw. from its 1 3/4" built-in speaker.

(Figure 7.) Here is a slide showing the receiver's small size. For use in high noise areas or when the leather carrying case is used, an accessory lapel speaker can be plugged into the unit. (Figure 8.) Also available is a hearing aid type earpiece with volume control for extremely noisy situations. Inside the radio you can see the modular printed circuit construction. (Figure 9.) This unit shown on the slide is standard squelch--We will also have available a selectively-called version of the receiver which will allow up to 10,000 individual selective calls. Note the miniature sealed Permakay filter for determining receiver selectivity. The receiver is available in either wide or narrow band versions.

(Figure 10.) Battery replacement is accomplished in this manner. By the way, receiver battery life is anywhere from 120 to 200 hours -- over a month of 8 hour days. Both mercury battery versions and nickel-cadmium rechargeable battery models are available. A picture of the receiver major parts shows the king-size speaker, egg crate and individual modules for easy servicing.

(Figure 11.) Now, let's focus our attention on the companion transmitter. The transmitter has a full 1.0 watt of RF power in the high or low frequency bands, and is capable of two-channel operation where desired. Instantaneous deviation control allows operation with either wide or narrow deviation. The unit I have in my hand has the antenna built into the microphone cord. (Figure 12.) Here is a slide of the model of this unit with optional external antenna that pulls out to a full 1/4 for maximum range. This view shows the inside of the transmitter exposing its printed circuit construction.

(Figure 13.) This product---two-way pocket communications with a top-notch receiver and a high quality maximum power transmitter---opens the door to improved operational efficiency and personal safety.

Some seven years ago, experiments were started at Motorola regarding transistors in mobile radio. (Figure 14.) Here is a unit tested in 1952 which had some audio and IF transistors in it -- (Figure 15.) In 1953, field tests were run on the "little job" with fold-out chassis for easy serviceability.

(Figure 16.) In 1954, equipment with transistors was placed in service in a 100 customer limited common carrier activity which is operated by Motorola in Phoenix, Arizona. (Figure 17.) Here is an installation in a station wagon. (Figure 18.) In the summertime in Phoenix, the 110° temperature offered excellent experience with heat problems in the transistor.

(Figure 19.) In 1956, this unit, which we referred to as the "Transistodyne", was developed and field tested. The receiver here was almost completely transistorized and the heat was controlled by providing a special heat sink for heat radiation of the transmitter tubes.

Over a period of six years, the boundaries of transistor application to mobile and portable communications equipment have thus been challenged and progress has been made. Transistors of the high quality required for the land mobile services are still expensive, but in a service where reliability is so important, the improved reliability of the unit and its resultant lower operating cost balance this increased cost.

Land Mobile radio users require mature equipment which has evolved from the many years of continuous development of circuits and

mechanical designs which were thoroughly proven in the field. (Figure 20.) Three months ago, new Motorola MOTRAC two-way radio was announced. This equipment contains a fully transistorized receiver and completely transistorized power supply. MOTRAC stands for Motorola Transistorized Advanced Communications. (Figure 21.) Here is a picture showing a vehicle test installation with which comparative tests between the MOTRAC transistorized radio and various models of standard tube line of TWIN V radio were run.

MOTRAC radio equals or betters the major performance characteristics of our tube sets, yet gives all the advantages of transistors and printed circuitry. The basic advantages that the transistor can offer are utilized to the fullest in MOTRAC radio:

First and foremost - increased reliability - There are no tubes in the receiver and no power supply for the receiver - it works directly from vehicle battery. Also the power supply is completely transistorized - no vibrators to fail.

Second - Low current drain - On standby, the entire radio draws 1.8 amperes from 12 volts which includes the transmitter filaments - thereby eliminating need for heavy duty generators.

With battery saver switch the transmitter filaments can be turned off. Total radio set drain is then only about 350 ma.

Small size - the radio is only about 50% of the size of tube radios.

Light weight - the entire radio weighs less than 25 lbs. compared to 43 lbs. of tube radios.

Now, let me tell you some of the specifics about this new radio. (Figure 22.) It has a plug-in control head so that the basic unit can be mounted in the front of a vehicle or in the trunk.

Because of its small size, the MOTRAC radio can be mounted in the trunk of a car without taking any appreciable trunk space. (Figure 23.) In fact, because of its changed form factor, it can be mounted on its side off in a corner of the trunk leaving almost complete utilization of space for other items. (Figure 24.) It can be mounted under seats or overhead in trunks or in many other small areas heretofore unused.

It will be available in both the 25-50 Mc. band and in the 150-174 Mc. band. (Figure 25.)

Here is a slide showing the inside of the unit. The receiver is directly behind the front panel, then comes the transmitter power supply, followed by the transmitter. The transmitter power output tubes are concealed by the easily removable heat sink at the rear of the radio.

(Figure 26.) Here is a shot of the bottom of the unit showing the complete accessibility of all connections. (Figure 27.) This is an exploded view of the double superheterodyne receiver (minus the RF section), showing all its printed circuit modules. The receiver has a sensitivity of .4 microvolt for 20 db. quieting in the low and .6 uv. in the 150 Mc. band. Of course, it will be available in both split and wide band versions with spurious and image rejection of greater than 100 db. The transistorized audio output is 5 watts, sufficient to override any ambient noise conditions.

(Figure 28.) This next slide shows a close-up of the receiver with an IF strip folded out to show easy accessibility for servicing -- Of course, you'll probably never have to service this radio, but you may want to take it apart and look at it once in a while.

(Figure 29.) Here is a view of the transmitter printed module and the complete transmitter with its die cast chassis showing placement of the RF power output tubes. The transmitter will be available with RF power outputs of 30 and 50 watts in the 25-50 Mc. band and 25 watts in the high band and with spurious emissions held 85 db. below the carrier. The transmitter also incorporates a transistorized Instantaneous Deviation Control Circuit.

(Figure 30.) This slide shows the transistorized power supply together with its die cast heat sink utilizing Motorola MN62 power transistors. Of course, either noise squelch or Motorola Dual Squelch Private Line will be available.

In summary, through transistors, this design offers:

1. Increased reliability - completely transistorized receiver and power supply,
2. Performance with specifications equal to tube equipment,
3. Low current drain - 1.8 A. standby, 350 MA with battery saver feature,
4. Small size - 50% reduction,
5. Light weight - less than 25 pounds, and
6. Lower operating costs because of better reliability and lower drain in the vehicle.

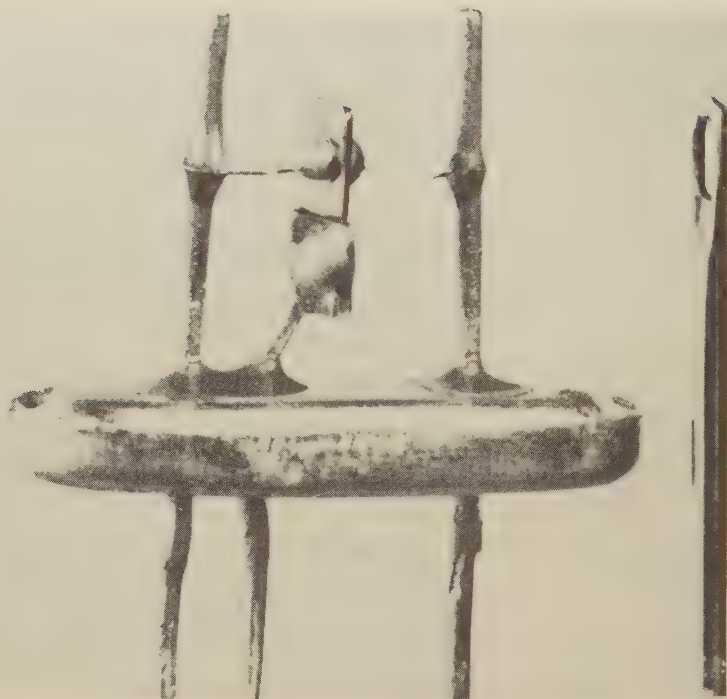


Fig. 1

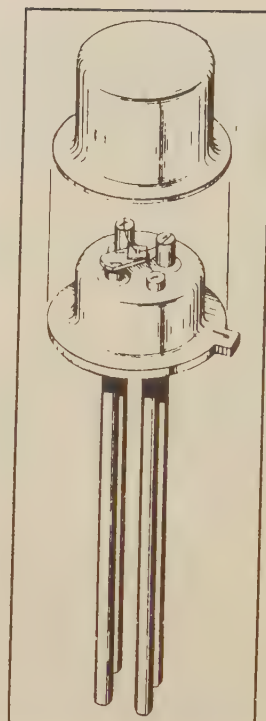


Fig. 2



Fig. 3

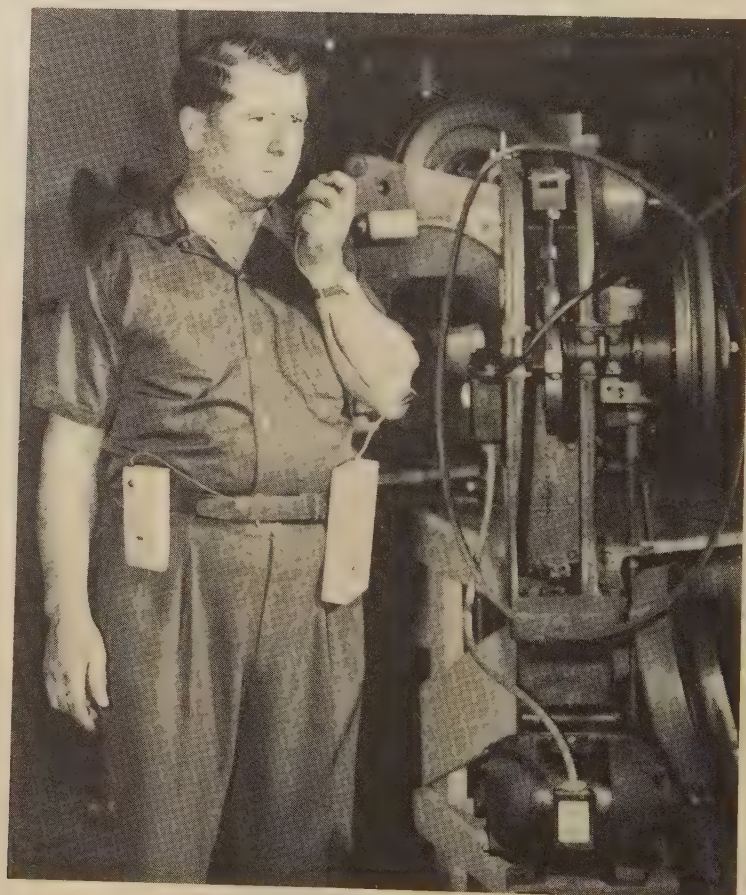


Fig. 4

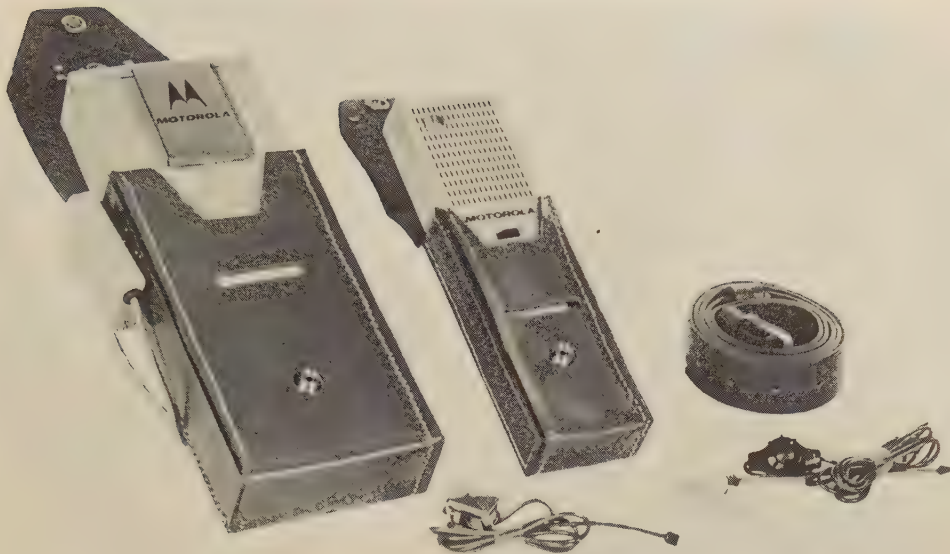


Fig. 5



Fig. 6



Fig. 7



Fig. 8

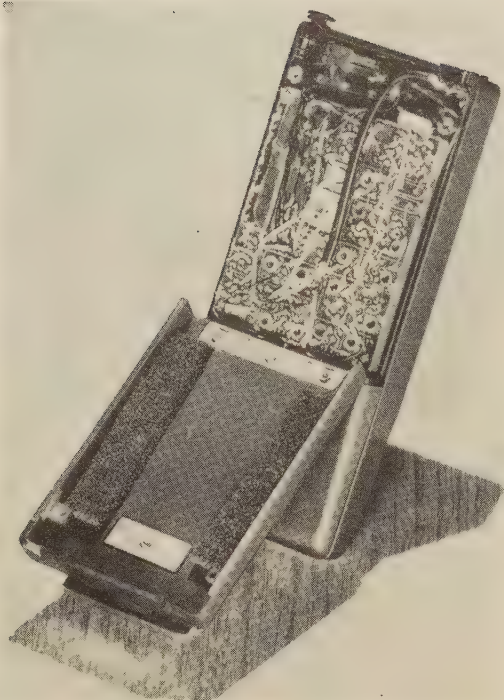


Fig. 9



Fig. 10

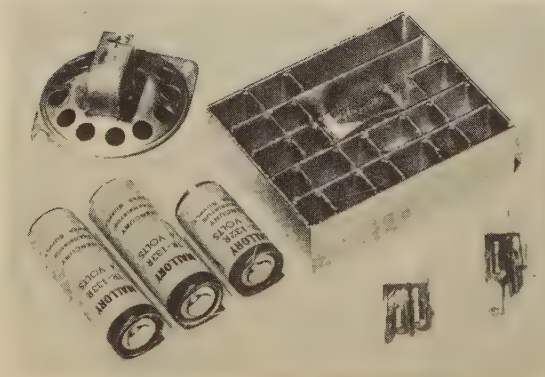


Fig. 11



Fig. 12

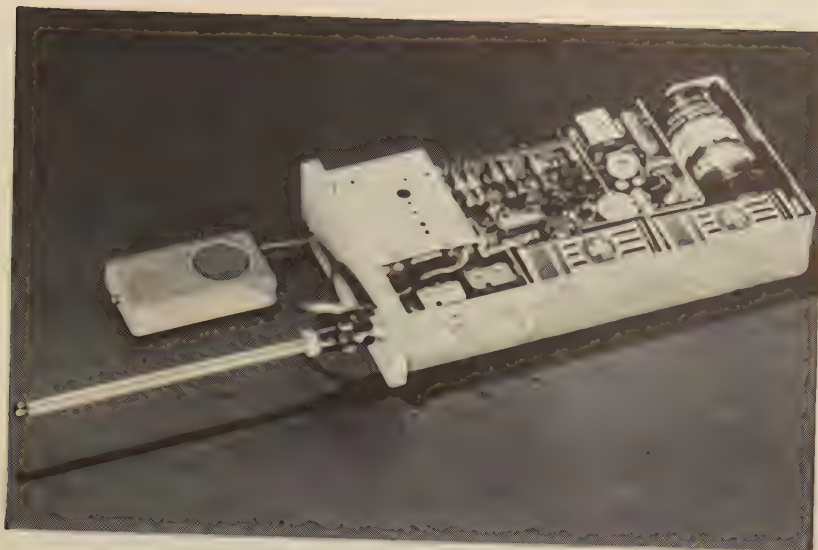


Fig. 13

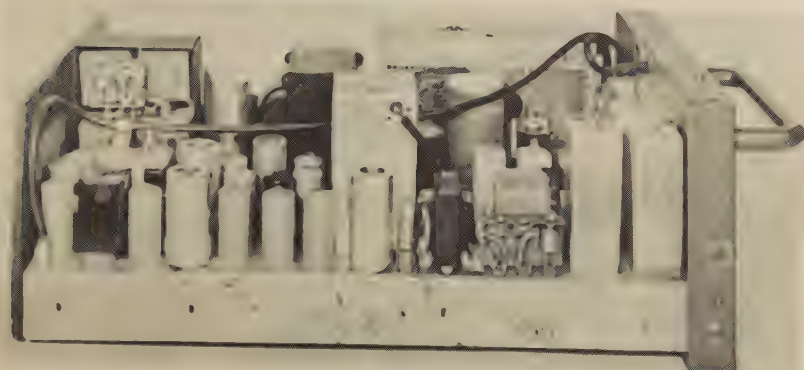


Fig. 14

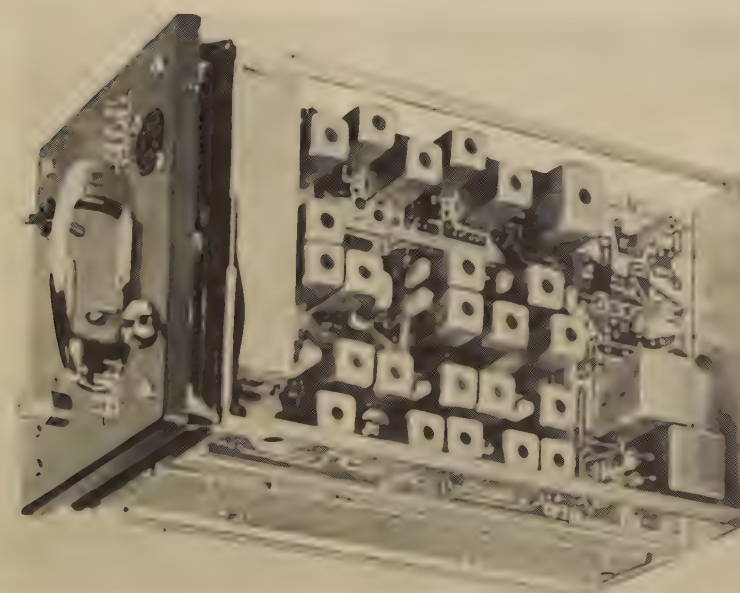


Fig. 15

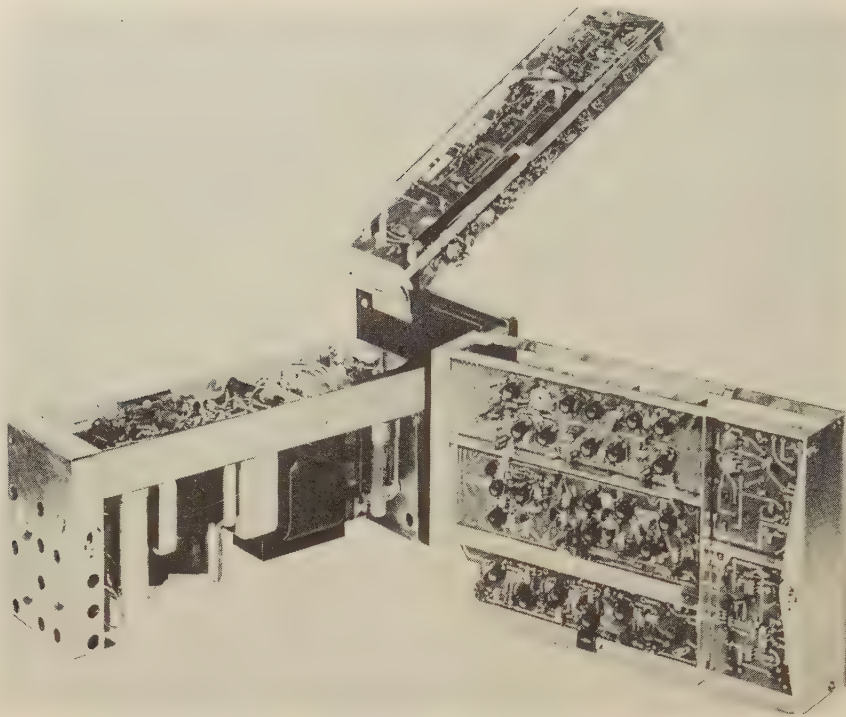


Fig. 16



Fig. 17

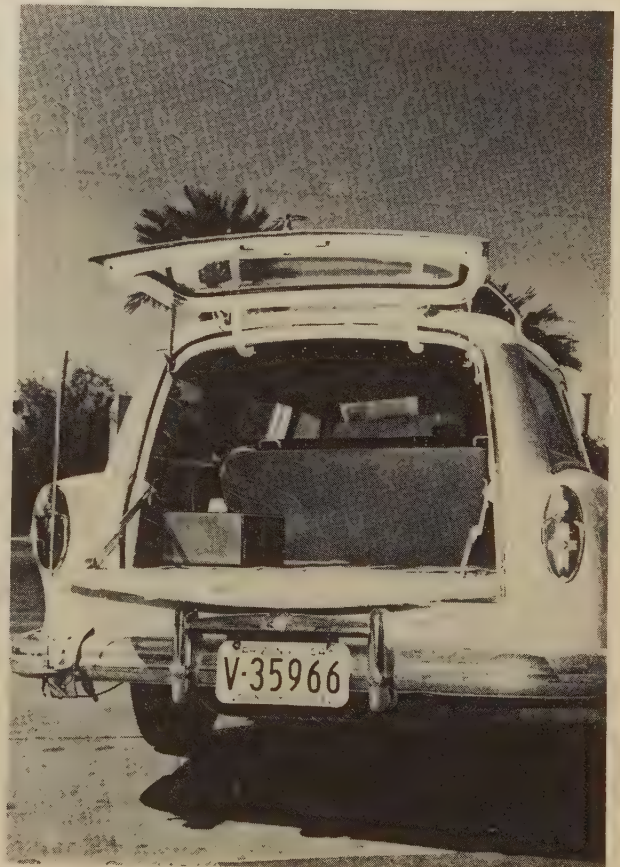


Fig. 18



Fig. 19

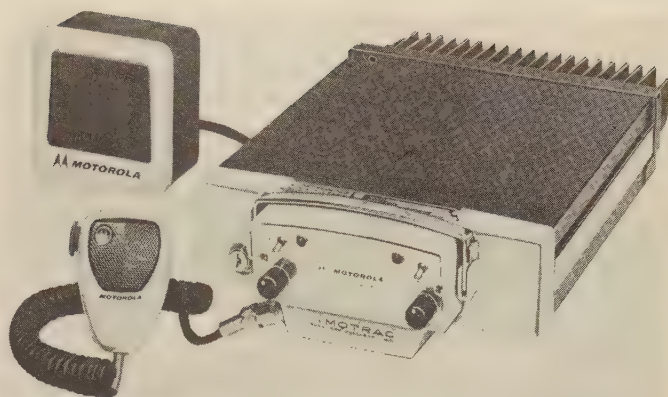


Fig. 20

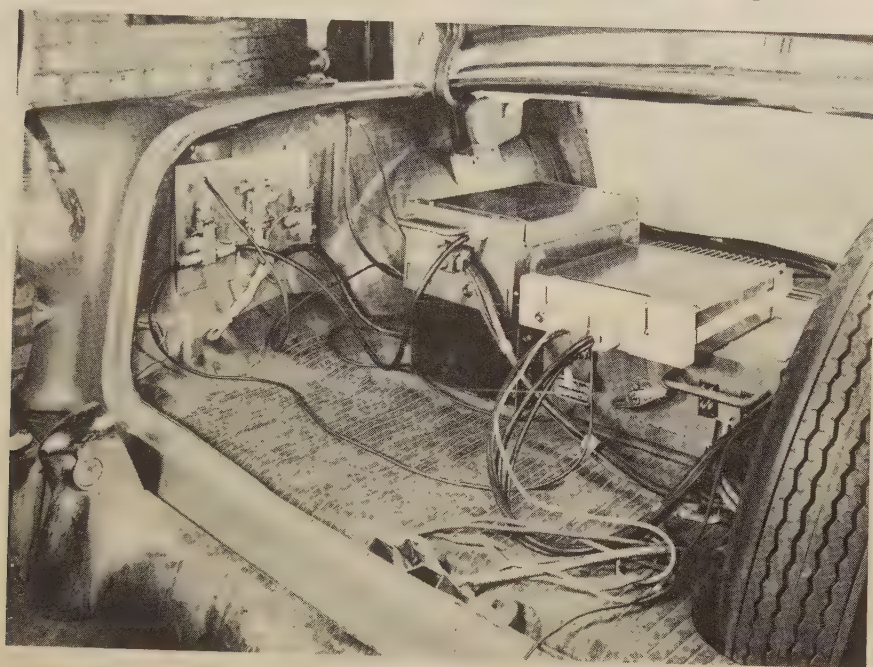


Fig. 21

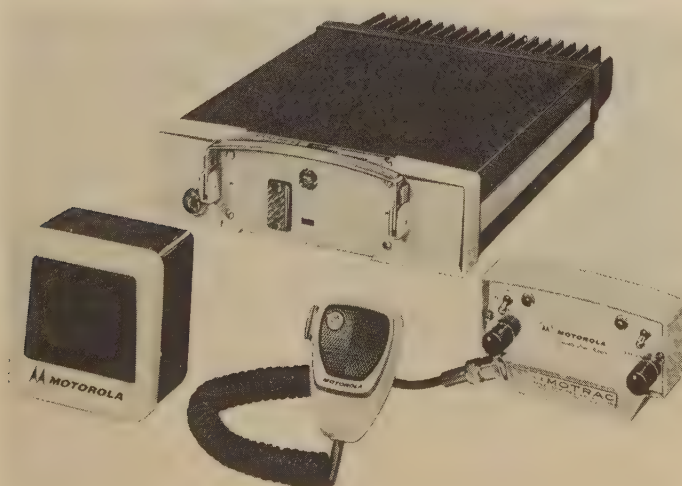


Fig. 22



Fig. 23

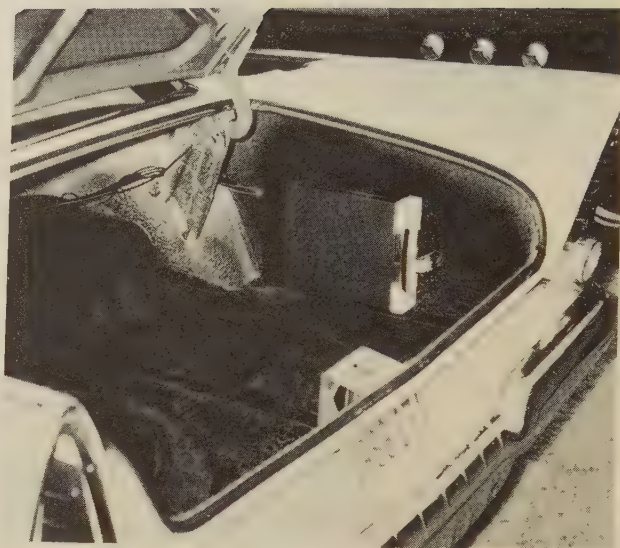


Fig. 24



Fig. 25

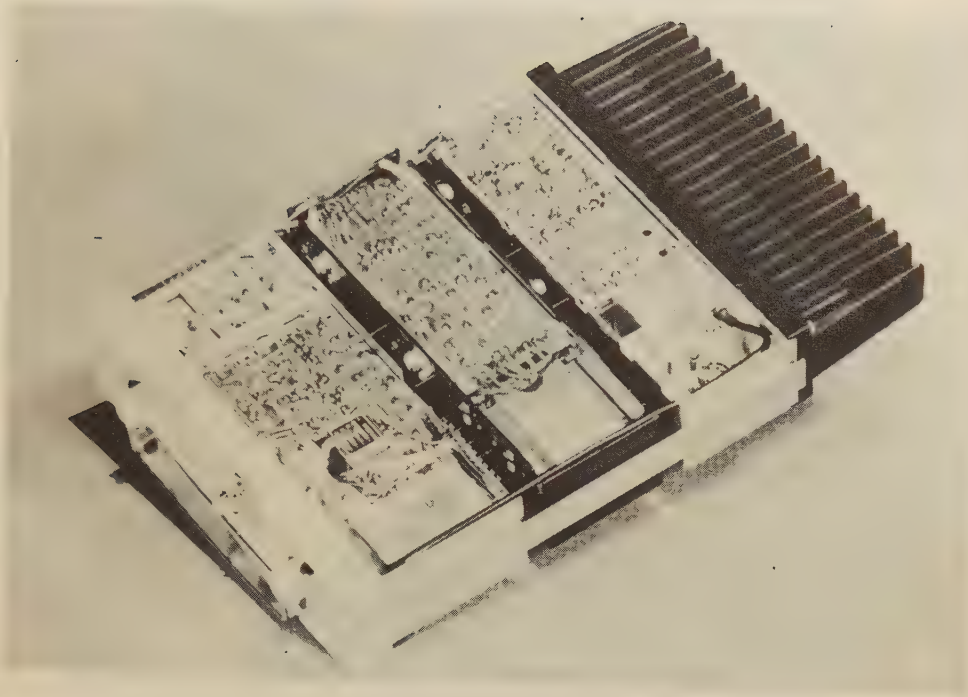


Fig. 26

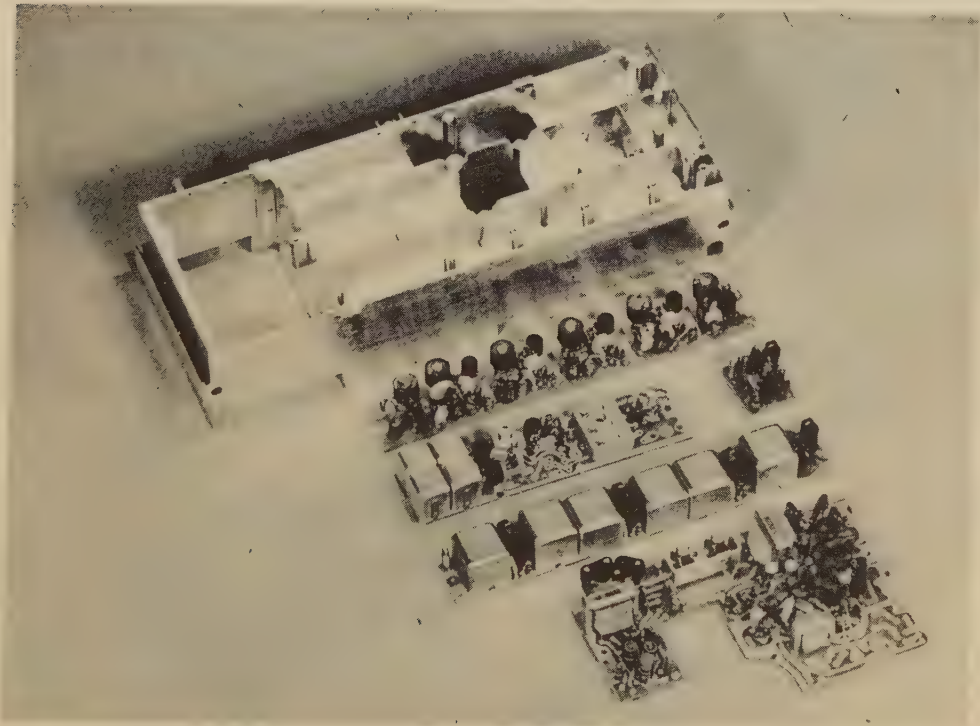


Fig. 27

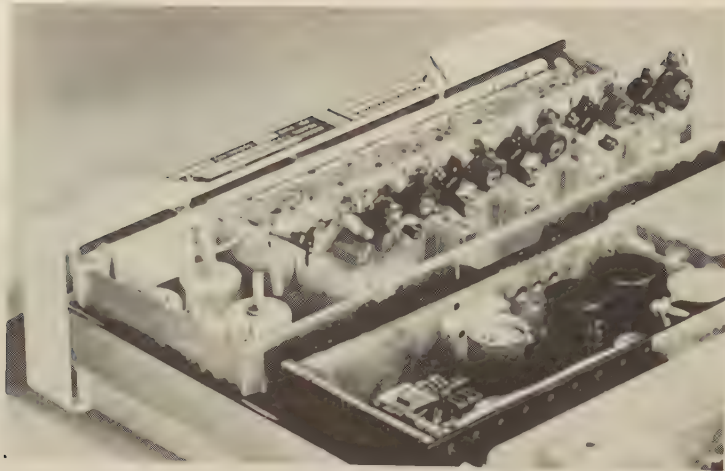


Fig. 28

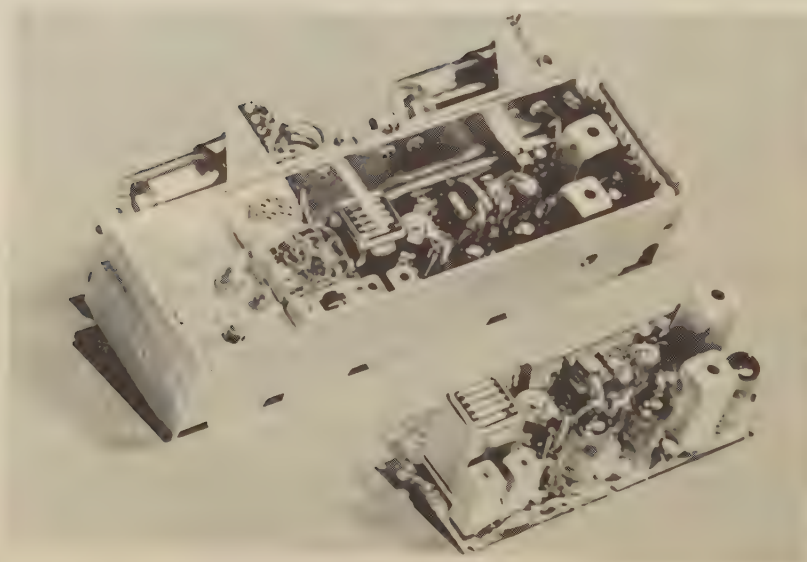


Fig. 29

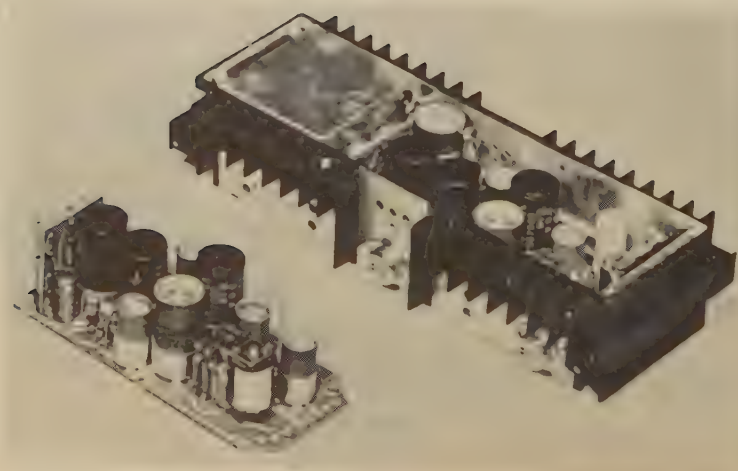


Fig. 30

BIAS CONSIDERATIONS IN TRANSISTOR APPLICATIONS TO COMMUNICATIONS CIRCUITRY

Arthur G. Manke
General Electric Company
Lynchburg, Virginia

One of the essential problems in the successful application of small signal transistors to communication receivers is the choice of proper bias potentials and the ohmic value of the resistors used to establish the bias potentials. The problem of proper bias must, of course, take into consideration the power dissipation requirement, the temperature range over which the transistor must operate and the value of the resistors used to establish the bias potentials.

Before considering factors involved with temperature range we will first consider transistor characteristics for operation at room temperature when using transistors of the type normally used in RF, intermediate, and audio frequency amplifiers. Figure 1A and 1B show a typical NPN and PNP transistor schematic with bias resistors set up for operation from a single battery. The two diagrams look very similar, however, the battery potential is reversed; for the PNP schematic the positive side of the battery is grounded and for the NPN transistor the negative side is grounded. The NPN or PNP transistor will function equally well regardless of which side of the battery is grounded. Also, it must be remembered that in a junction diode the situation regarding electron flow is quite different than that of the vacuum tube diode insofar as the semi-conductor material used can be changed from P type material to N type material by doping or changing the impurity of the semi-conductor material, consequently there is no inherent designation on the schematic diagram which tells the direction of electron flow such as there is in the case of the vacuum tube diode. The direction of the arrow on the emitter is the only indication on a schematic diagram of whether the transistor is a NPN or a PNP.

The transistor as viewed from the circuit appears to be two junction diodes with a common base. The base to emitter or base to collector diodes used individually do make very good diodes and it is common practice to use a defective transistor as a diode. You cannot, however, arrive at a transistor by putting two ordinary junction diodes together back to back. With battery potentials as established in Fig 1-B the direction of electron flow in the base to emitter diode is from the base to the emitter. (The emitter corresponds to the anode of the vacuum tube diode and the base to the cathode). The collector diode is a back biased diode and in the absence of current in the emitter diode no controlled current flows from the base to the collector, however, with forward current established in the emitter to base diode the electron flow in the collector diode is from the

emitter through the base to the collector. (The collector corresponds to the plate of the vacuum tube diode.)

In an NPN transistor the common base is the "P" material of the transistor and the collector and emitter are the "N" material. As a result of making the P material which separates the two N materials extremely thin (in the order of one-tenth thousands of an inch) the two diodes working as a single unit take on characteristics quite different from the double based diode and become a three terminal device having characteristics like the familiar vacuum tube, the collector like the plate and the emitter like the cathode. In other words by means of the proper potential between the base and the emitter the collector current can be controlled. The transistor is in reality a linear current amplifier and in order to accomplish current amplification the base to emitter diode must be biased to produce a small value of current in this diode. It is this small flow of current in the base to emitter circuit which provides electron carriers to produce the much larger emitter to collector current. This means that the base to emitter voltage should be .05 to .15 volts for the average low power transistor and these values of bias are the same for NPN as well as PNP transistors. If the DC bias is set up so as to cut off the forward

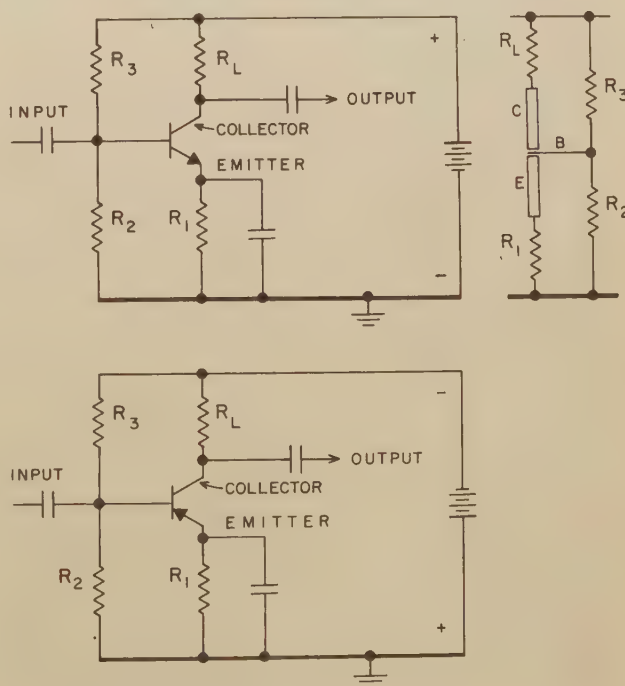


Fig. 1a (top) - NPN; Fig. 1b (bottom) - PNP.

current in this diode then the amplification property of the transistor will be reduced to zero. See Fig 2 for the relations of emitter diode current Vs base to emitter voltage and note that only a very small power input is required to establish this current.

The collector to base voltage must also be at least one half volt for controlled current to flow in the collector circuit or the other junction diode of the transistor. For a PNP transistor the collector must be negative with respect to the base and for a NPN transistor the reverse is true. The curves of Fig 3 show how rapidly the emitter current increases for very small emitter to base voltages. Note that an increase of slightly less than .20 of a volt changes the collector current from .50ma to 9.0ma or an increase of 18 to 1. It is no wonder that the transistor has been so popular as a switching device, and is equally attractive as an amplifier. Note the small effect base to collector voltage has on the slope of these curves. The 1.5 volt curve has essentially the same slope as the 12.0 volt curve, however, for AC application the power output available from the collector circuit will be proportional to the square of the base to collector voltage. Fig 4 shows the current in each diode for a 2N43 transistor. This curve,

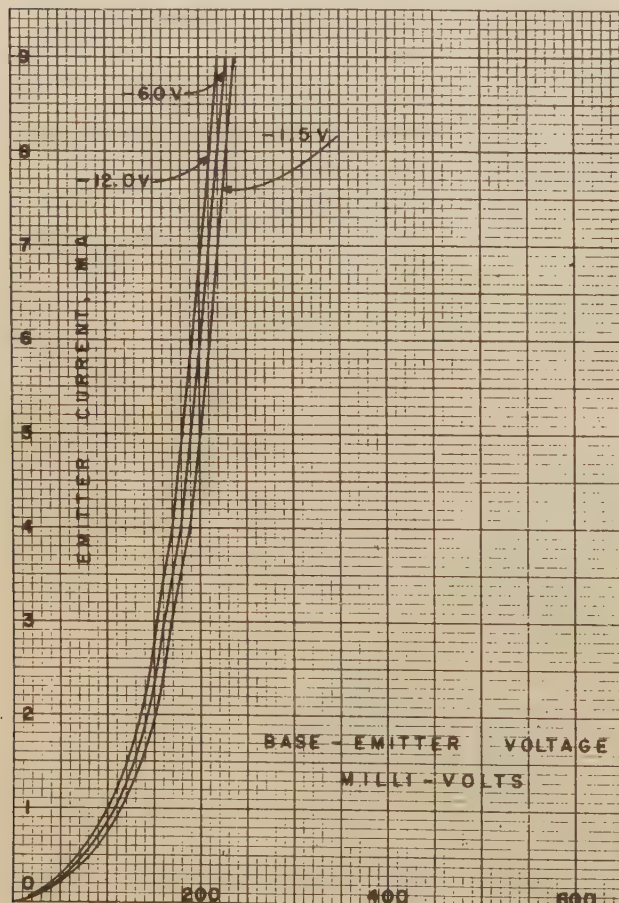


Fig. 2

therefore, shows the current amplification of this particular transistor and for most transistor applications thinking in terms of current or power amplification is more practical for design purposes. Fig 5 shows the power gain of the 2N43 transistor under the same conditions as used for 4. This figure is more impressive than any of the other curves and suggests one of the inherent characteristics of transistors which make them so capable as power amplifiers. This occurs because the internal collector to emitter impedance is high whereas the base to emitter or input impedance is very low in comparison. (One is a forward biased diode and the other a backward biased diode). Since the output impedance of the transistor is high, a high impedance load can be used for the output circuit consequently the power gain of the device is more favorable than the current gain shown in Fig 4.

We have seen certain facts regarding the bias voltages which we must have for each junction diode of the transistor when operating at room temperature and we have also admired the tremendous power gain which the transistor is capable of. We must now consider what happens to this rather bright looking picture when we take into account the matter of DC bias and transistor operation over a temperature range. There are two effects (which vary with temperature) present in the transistor - one in the base to collector diode and the other in the base to emitter diode.

One of these effects present in the collector junction of a transistor is the existence of a residual current, (sometimes called saturation current I_{CO}) and its variation over the temperature range which we normally encounter in communication services. This residual current flows through the base to collector diode with or without the application of battery voltage to the collector and is the un-controlled part of the collector current and, therefore, does not take part in the signal amplification process. The reason for the existence of the I_{CO} current in the collector diode is a subject which requires a treatise by itself and for the time being it will suffice to say that this current is dependent on the energy gap of the semiconductor materials used in producing the particular transistor. The I_{CO} current present in the collector junction of a transistor must, however, be carefully evaluated when setting up the ohmic value of the bias resistors such as R_1 , R_2 , and R_3 of figure 1. If this is not considered, the transistor may be limited to operation at essentially room temperature. Figure 6 shows a typical curve for variation of I_{CO} with temperature for a low frequency germanium transistor such as is used in the low IF amplifier of a mobile receiver. Note this current is 3.0 microamps at room temperature, essentially zero for temperatures below zero degrees and increases to 60 micro-amps at 65°C, which is well within the temperature range attained by communication equipment for many applications. The I_{CO} current flows from the collector diode through the load resistance and

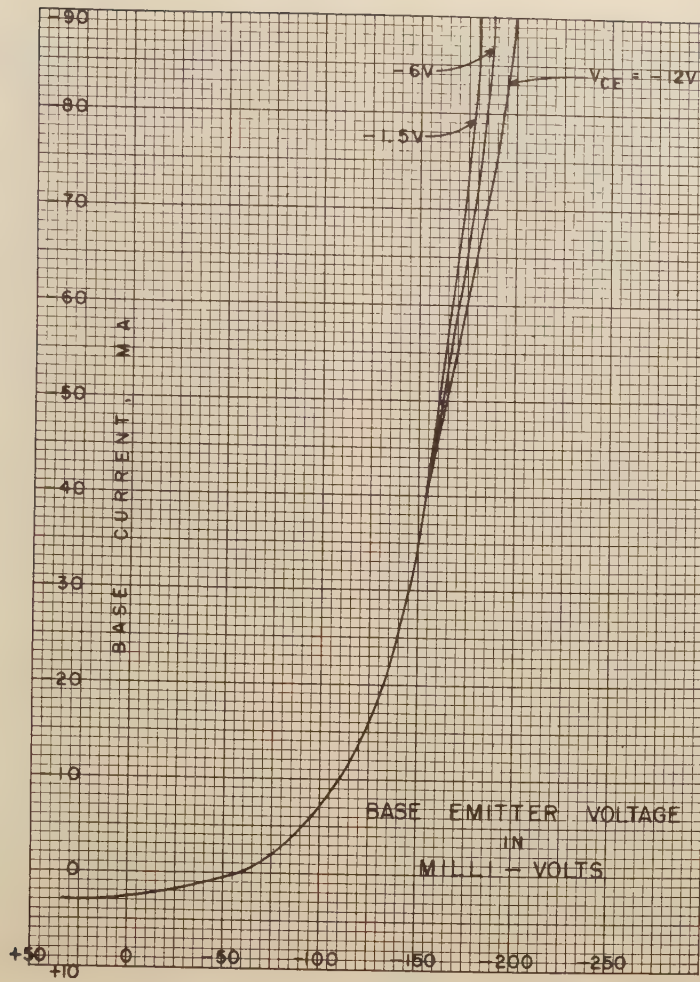


Fig. 3

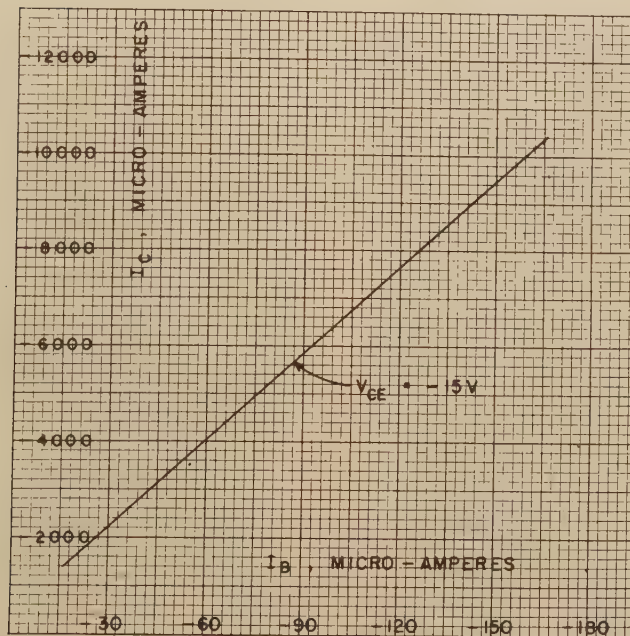


Fig. 4 - Collector current flow vs. base current flow with a -12 volt collector-emitter.

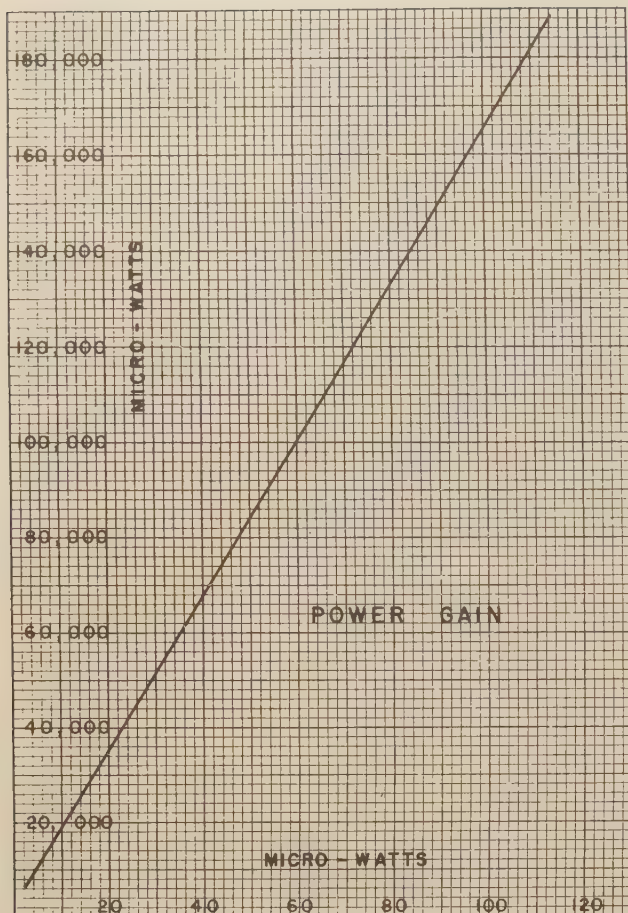


Fig. 5

back to the base through R_2 and R_3 in parallel. R_3 is usually much higher in resistance than R_2 , therefore, approximately 90% of the I_{CO} current flows through R_2 . A common value for R_2 would be 10,000 ohms. Consequently at 65°C the voltage drop across R_2 could change by .42 volts if R_2 is 30,000 ohms. This is a very large change in bias and if R_1 and R_2 are not properly proportioned the increase in collector current cannot compensate for the change in bias across R_2 (due to I_{CO}) and the transistor is then in danger of "Run-away." The rapid increase in collector current with change in the base to emitter voltage was illustrated in Fig 3. This figure also illustrates how important it is to maintain the correct bias voltage in the base to emitter diode in order to keep at an efficient operating point. Assume an operating point of .15 volts (emitter to base) and note that an increase or a decrease of .20 volt would upset the linear operation of the transistor. The value of the I_{CO} current is the same for NPN or PNP germanium transistors, however, for silicon transistors the I_{CO} current is much smaller at any particular temperature. To obtain the same value of I_{CO} current in a silicon transistor as is present in a germanium transistor at 100°C it would be necessary to raise the temperature of the silicon transistor to approximately 312°C. This shows considerable

superiority for the silicon transistors as they would not require careful attention in the matter of compensating for I_{CO} when operating over the temperature range of -30°C to +65°C.

This brings us to the question of what are desirable values for the biasing resistors R_1 , R_2 , and R_3 of Figure 1 for the germanium transistors having an I_{CO} characteristic as shown in Figure 6. This, of course, depends on the application of the transistor and where the usual low level amplifier stage (RF, IF, or audio) is involved the biasing resistors can be chosen so as to have a current stability factor (S_1) ranging from one to approximately ten, however, for applications of a somewhat more critical nature the current stability factor should be held to one and less as the variation of the emitter and collector current frequently results in the variation of other parameters of the transistor. The current stability factor is defined as the ratio of the base to ground DC resistance to the emitter resistor or

$$S_1 = \frac{\frac{R_2 \times R_3}{R_2 + R_3}}{R_1} \text{ of Figure 1}$$

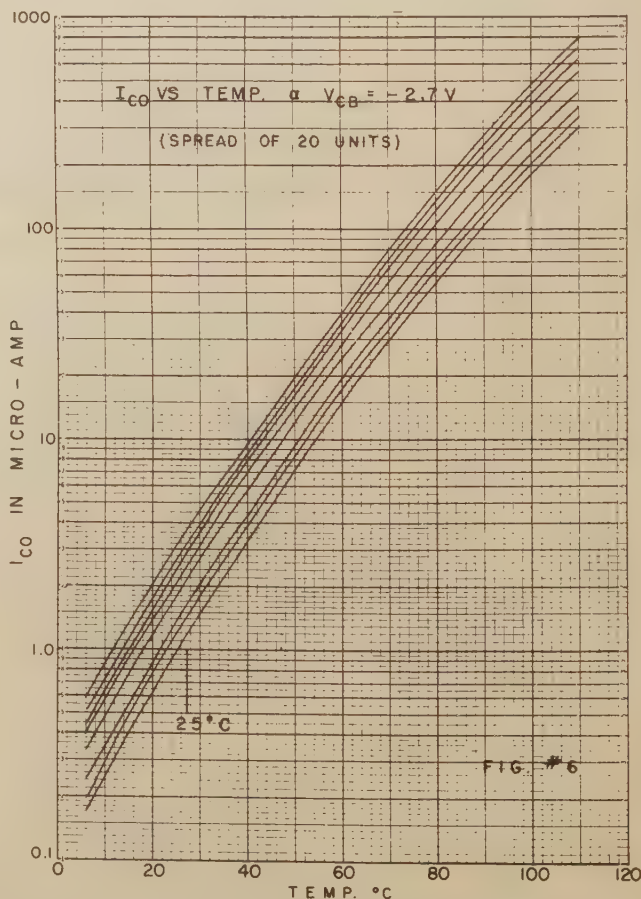


Fig. 6 - High frequency PNP alloy transistor type 2N450 lot PX, mfg. date 5/2/57.

Various methods in addition to good current stability factors have been suggested for controlling I_{CO} and among these is the use of a DC feed back resistor from the collector to the base and the use of a compensating diode having characteristics identical to the base to collector diode. Figure 7A and B show the circuit used to accomplish these methods of compensation. In Figure 7A R_4 is the feed-back resistor and R_4 improves I_{CO} stabilization since the current flowing through R_2 , due to the presence of R_4 , decreases as I_{CO} increases. Figure 7B illustrates one method of using a compensating diode (CRL). In this case the reverse saturation current I_{CO} of CRL must be essentially equal to the stability factor S_1 of the transistor circuit multiplied by the I_{CO} current of the transistor. This is not difficult to accomplish if CRL and the transistor collector diode are made of the same material. The compensation occurs due to the saturation current I_{CO} of the collector diode flowing through R_2 and the saturation current of CRL flowing through R_1 and if R_1 and R_2 are approximately equal (R_2 large as compared to R_2) and the diode currents in the opposite directions then the base to emitter potential of the transistor will remain essentially constant with variations in temperature. Where the emitter is well bypassed this method of applying the compensating diode keeps CRL at AC ground potential which is a very desirable feature.

In addition to the I_{CO} current originating in the collector diode there is another characteristic of the small signal amplifier transistor with respect to temperature which must also be considered in setting up the resistors to obtain the necessary bias voltages. This effect is best illustrated by the curves in Figure 8. Note that at a temperature of -30°C 290 milli-volts are required (base to emitter) for one milli-ampere of collector current, whereas at

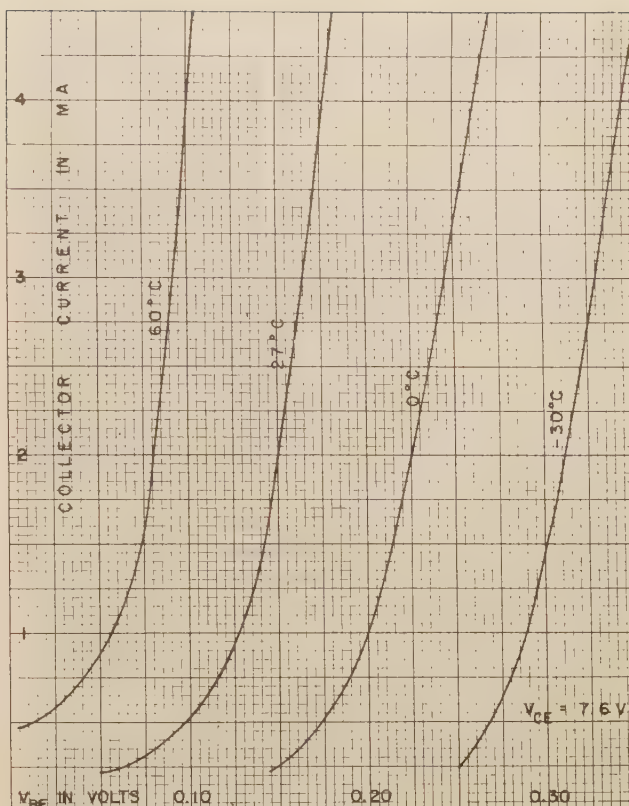


Fig. 8

$+60^\circ\text{C}$ only 50 milli-volts are required. Compensation to counteract this effect is especially important in obtaining minimum distortion and constant audio output from a class "B" audio stage over the temperature range. From the curves of Figure 8 we see that it is necessary to shift the bias potential (base to emitter) 235 milli-volts for a temperature range of 90°C or approximately 2.5 milli-volts per degree in order to keep the collector current at the same value over this temperature range. This could be accomplished by shifting the resistance of R_2 of Fig 1 in the proper manner over the temperature range. Since the effect illustrated in Figure 8 is present over the entire temperature range it can be compensated to a reasonable approximation by the use of the negative temperature coefficient resistors also known as thermistors or ceramic resistors. The compensation curve of a thermistor does not match the junction diode characteristic over the temperature range and where more accurate adherence to the diode curve is required a resistor network of the type shown in Figure 9A and 9B may be used in place of R_2 . The resistance of the network shown in Figure 9 for a particular temperature is given by:

$$R_A = R_3 \frac{R_1 R_2 + R_T (R_1 + R_2)}{R_1 R_2 + R_2 R_3 + R_T (R_1 + R_2 + R_3)}$$

$$\text{and for 9B is } R_B = \frac{R_1 R_2 + R_1 R_3 + R_2 R_3 + R_T (R_1 + R_3)}{R_1 + R_2 + R_T}$$

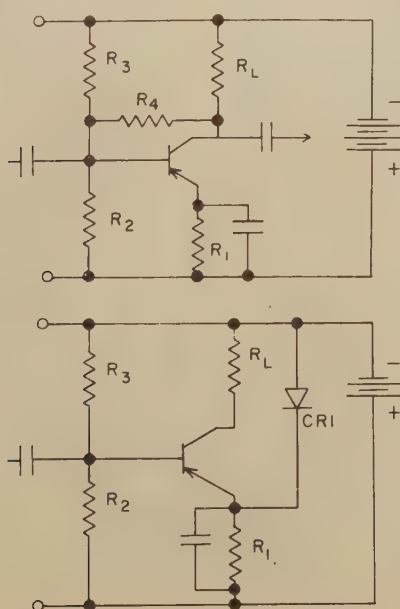


Fig. 7a (top) and 7b (bottom).

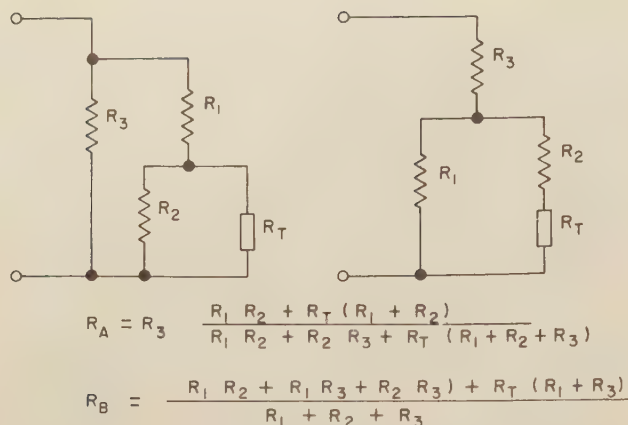


Fig. 9a (left) and 9b (right) - Shaping network.

where R_T = the resistance of the thermistor at a particular temperature. Another method for accurate compensation of the base to emitter diode effect is the use of a diode as shown in Figure 10. Figure 8 showed how the conduction characteristic of the base to emitter diode improves with temperature and if the emitter current is to be held at a constant value a reverse voltage of 2.5 mv per degree C must be introduced. This can be accomplished by addition of diode CR1 so as to apply its voltage in the reverse direction to both transistors.

We have seen how temperature range affects the small signal type of transistor in regard to DC bias and also some suggested solutions for operation over a temperature range. We will now look at some of the transistor stages of the General Electric receiver shown in Fig 11 which operates over the -30 to +60° temperature range and see how the bias problems were solved in this portable equipment.

Figure 12 shows the resistor values used in a typical low IF amplifier stage of the GE portable receiver. R_1 and R_2 are 3300 ohms and R_3 is 12,000 ohms. Calculating the current stability factor shows S_I to be .785. Since the stability factor is even less than one, this stage is certainly in an excellent position to compensate itself against the two effects described above, because the emitter to ground potential would

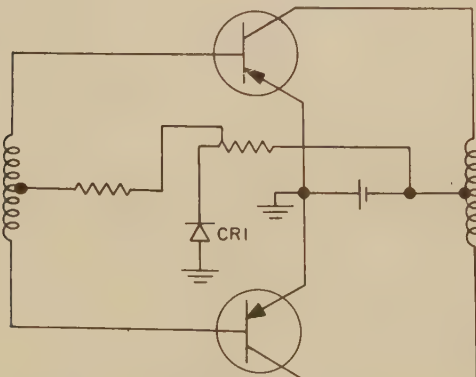


Fig. 10

increase at a faster rate than the ground to base potential. Let us now take a look at the situation with respect to the emitter to base diode. If you carefully measure from base to emitter you will find the base to emitter potential to be about one tenth of a volt with the emitter positive. The total drop across the emitter resistor is between 2.0 and 3.0 volts for a supply voltage of 12.0 volts. On this diode we would be concerned with the possibility of dropping out of conduction at -30°C from the the information given by Figure 8. Here again the value in ohms of the bias resistors R_1 and R_2 are safety guard against this difficulty. As the activity of this diode decreases due to lowering temperatures note that a degenerative action takes place and that the resulting action is to decrease the collector current, and the voltage drop across R_1 . This will increase the forward voltage across the emitter to base diode since the base is tied to a fairly stiff bleeder. We, therefore, are in no danger of cutting off the current in the base to emitter diode due to operation at -30°C. A measure of how well a transistor stage bias system is designed can best be judged from a curve which shows collector current Vs temperature. The bias system which most nearly accomplishes constant collector

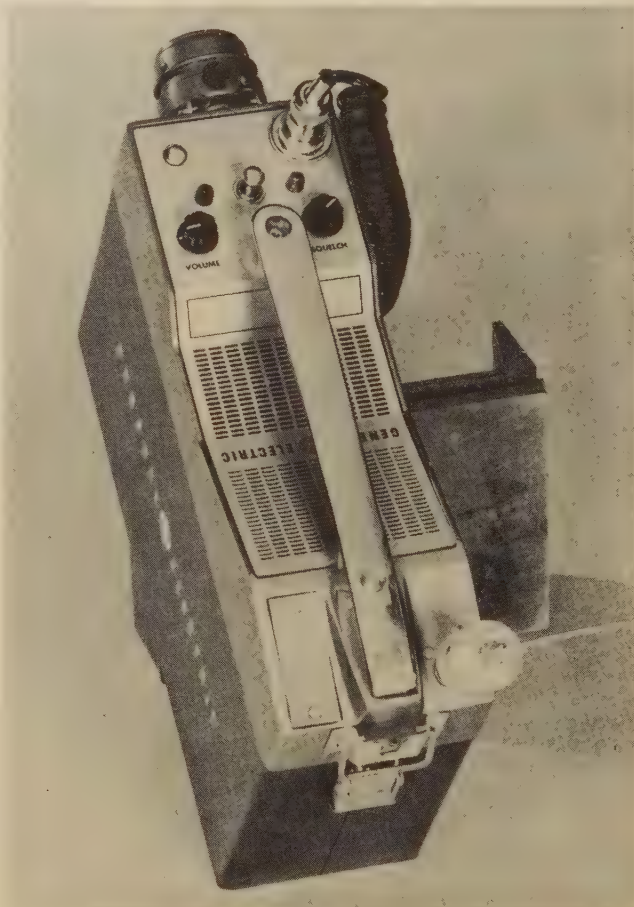


Fig. 11

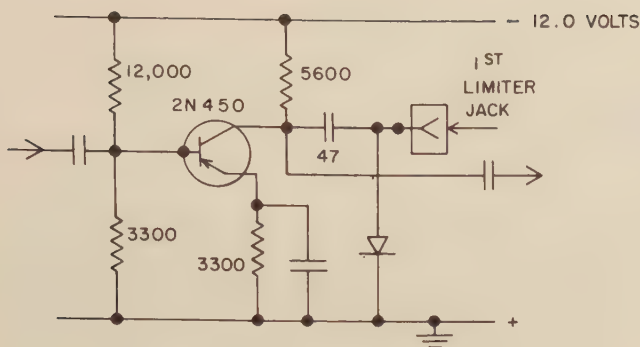


Fig. 12 - Low IF stage.

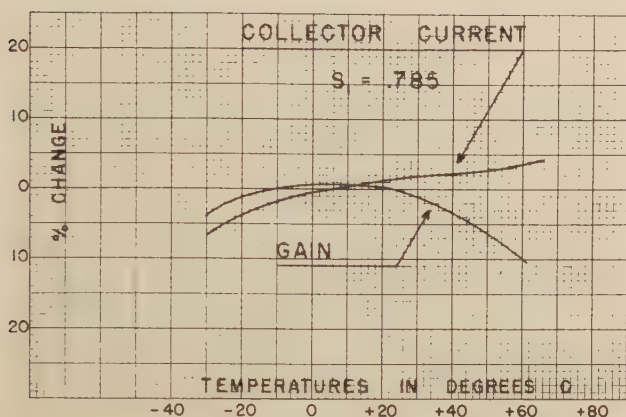


Fig. 13

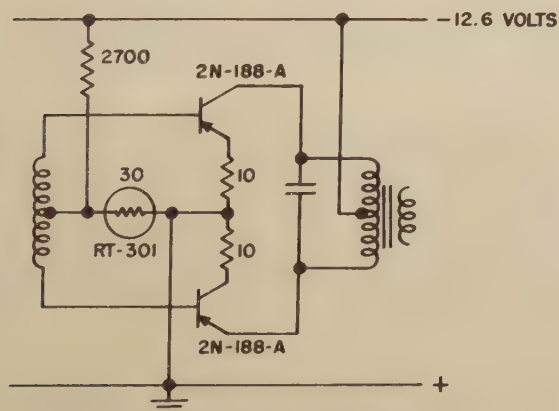


Fig. 14

current is, of course, the best system as such a system allows the transistor to operate to the highest possible temperature and at the same time results in the smallest variation of the AC parameters of the transistor. Figure 13 shows this curve for the typical IF amplifier stage shown in Fig 12 and also shows the variation in

gain of this stage with temperature. Note that up to 65°C the 2N450 germanium transistor shows only a 11% reduction in gain and 4.0% change in collector current, at -30°C the reduction in gain is 4.0% and the change in collector current is 7.0%.

The other stages of the receiver which are equally critical of bias voltages are the first and second converters and the multiplier stage. These stages are biased in essentially the same way as the IF stage cited above, that is with good current stability factors, and therefore, operate with essentially no degradation over the temperature of -30° to $+60^{\circ}\text{C}$.

In figure 14 is shown the class "B" output stage of the GE portable receiver which uses two 2N188A transistors. In this case a thermistor or negative temperature compensating resistor is used to keep the output essentially constant over the temperature range. RT-301 is the compensating resistor and has a change of .3% per degree C. The current stability factor S is 2700×30 or 3.0. This stability factor is

$$\frac{2730}{10}$$

sufficient to provide safety against excessive collector current due to increasing I_c with high temperature, however, to match the base to emitter characteristic shown in Figure 8 the thermistor is used, and under this condition the variation in output does not exceed 4.0 DB over the temperature range.

From the above it is seen that by the proper attention to stability factor in setting up the bias resistors the small signal level germanium transistors such as RF, IF, converters, etc. can be made to operate satisfactorily over the -30° to $+65^{\circ}\text{C}$ temperature range with relatively simple bias compensation. The higher level audio output stage did require a special compensating resistor in order to hold the output constant to 4.0db over the temperature range.

References

1. R.F. Shea et al Transistor Circuit Engineering Wiley - New York 1957
2. H.C. Lin and A.A. Barco - Temperature Effects in Circuit Using Junction Transistors Transistors I RCA Lab Publication
3. E. Keonjian and J.S. Schaffner - "The Shaping of the Characteristics of Temperature-Sensitive Elements" Elect. Eng. Oct. 1954

TRANSISTORIZED POWER SUPPLIES FOR HIGHER INPUT VOLTAGES

Lester S. Pearlman
Sperry Products, Inc.
Danbury, Connecticut

Transistor power supplies answer a serious need in communications equipment. A variety of voltages are needed to operate the equipment, including higher voltages for transmitter operation. The available power in various mobile equipment includes 6, 12, 24, and 72 volt storage batteries. Two general methods of voltage conversion were used in the past. One included rotating equipment of various types such as dynamotors, motor-generator sets or alternators. The second method consisted of interrupting the direct current through rapid switching and applying this interrupted direct current to the primary of a transformer. The various secondary windings of the transformer are used to step the voltage up or down as required. In the past, vibrators were used to make and break the primary circuit and supply interrupted direct current.

The primary difficulties with both these methods are the necessity for frequent maintenance and the generating of hash. In both cases there are sparking contacts. In the rotating equipment the brushes spark and wear, and in the case of vibrators, the make-and-break contacts flash at each interruption. Radiation from the sparking contacts increases the ambient noise and limits the receiver sensitivity. The contacts themselves pit and wear with use, causing equipment failures and requiring frequent maintenance. Finally, the components used in either system are quite heavy, usually weighing considerably more than the receiver and transmitter they are supplying.

A more recent innovation has been the use of switching transistors instead of vibrators. The immediate advantages of this change are obvious: no sparking, no moving parts, no generation of hash which limits the receiver sensitivity, and no pitting or wearing of contacts. Transistors operate because of their crystal configuration. There are no parts to wear or to be used up. Except from such causes as contamination or damage, the transistors should last more or less indefinitely.

Let us first look at power transistors that are used for this type of application and determine what characteristics are most desirable. We need not worry about the sparking; it does not occur with transistors. We find there are three characteristics we should like to see in a transistor, and these are similar to those expected in a good switch. We should want the transistor to close instantly with very little loss or volt drop through it. Also, we should like it to handle fairly heavy currents. Finally, we should like the transistor when open to have a very high impedance and withstand high voltages without breaking down.

Figure 1 shows the construction of the typical power transistor. The entire bottom, which is

made of copper approximately 1/8 inch thick and 1 inch in diameter with a heavy copper stud, is part of the collector and helps dissipate the heat generated in the transistor during operation. The germanium crystal itself is a very thin square approximately 3/8 inch by 3/8 inch. The top view shows a center dot and two concentric rings. The center dot and outside ring are the base connec-

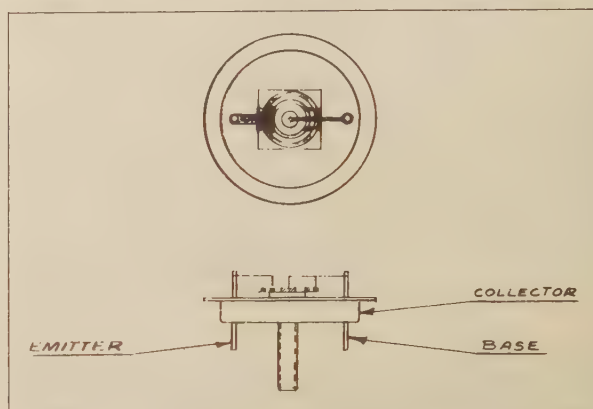


Fig. 1 - Transistor.

tion, and the middle ring is the emitter. The space between the rings is very small and the ring contact area is comparatively large, as are the contacts.

The heavy contacts, the close spacing between elements, and the heavy copper plate connected to the collector -- all contribute toward making this unit have extremely low volt drop and loss with heavy currents. When the base is biased to give saturation current through the transistor, we find that the emitter-to-collector drop is of the order of two or three tenths of a volt with emitter currents as much as three amperes.

The heavy components and close spacing detract however from the desired characteristics during open circuit operation. In this case we would like to see low leakage current and in certain applications the ability to withstand comparatively high voltages. It is the lack of ability in transistors to withstand higher voltages that is of special interest here. Typical manufacturers' ratings for collector voltages are 40 volts, 80 volts, and for certain expensive models, 100 volts.

Now let us look at a typical transistor switching circuit (Fig. 2). The two emitters are connected directly to the positive power terminal. The two collectors are connected through the transformer winding to the negative power terminal. The bases are connected through a transformer winding to a bias point between resis-

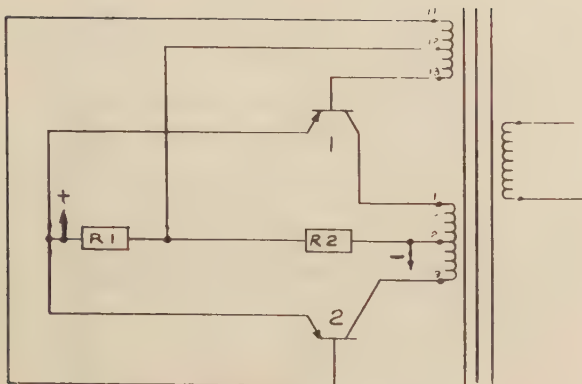


Fig. 2 - Switch circuit.

tors R1 and R2, so that they are somewhat more negative than the emitters. Therefore, the transistors are biased to conduct.

Since no two transistors or windings are identical, one of the transistors begins to conduct more than the other. Let us assume that transistor 1 conducts more than transistor 2. Transistor 1 is biased to saturation, the current through it being limited by the inductance of the winding. The positive pole of the applied voltage is substantially across the winding connections 1 to 2, and the flux rises at a constant rate. The feedback winding is connected to the base with such polarity that, as the flux is rising through the current flow through transistor 1, the base of that same transistor is maintained negative. The base of transistor 2 is kept at cutoff, so that no current flows through transistor 2.

This condition of maximum current flow through transistor 1 and an absence of current flow through transistor 2 continues until the transformer core reaches saturation. When this occurs, the rate of change of flux falls to zero. This decrease in the rate of change of flux reverses the voltages applied to the two bases so that the voltage applied to the base of transistor 1 is now in the positive direction, tending to cut that transistor off more rapidly. The voltage applied to transistor 2 is now negative going causing that transistor to conduct. The flow of current due to these applied base voltages is now from 3 to 2 on the transformer winding, accelerating this flip over. Transistor 2 conducts as did transistor 1 until the core saturates in the opposite direction when the process is once again reversed. The transistors are thus switched on and off alternately.

Each time a transistor is switched on, it applies almost the entire source voltage to its half of the transformer winding, the drop through the transistor itself being almost negligible. In 6 volt and 12 volt applications, if the drop across the transistor itself when it is conducting is excessive, additional transistors may be placed in parallel to reduce the drop. Since the drop through the transistor is comparatively small, the circuit acts as if the applied voltage were alter-

nately hooked directly to the transformer winding. Therefore, the wave shape of the voltage across the transformer is a square wave. See Fig. 3. The top half, for example, obtains when transistor 1 is conducting and the bottom half obtains when transistor 2 is conducting.

Notice in Fig. 2 that the two emitters are always connected to the positive pole. The two bases are biased only slightly differently from the emitter itself and are therefore comparatively close in voltage. But let us see what happens to the collectors.

When a transistor is conducting, the collector of that transistor is almost at the same voltage as the emitter, differing only by the very small volt drop through the transistor. However, when that transistor is not conducting, the emitter remains at the positive voltage, and the collector goes more negative than the source because an equal and opposite voltage is induced in its half of the transformer winding by the current through the half winding of the other transistor.

The voltage that appears across the transistor when it is not conducting is therefore approximately twice the applied voltage. If the applied voltage is 12 volts between the emitter and the center tap of the transformer, then in the nonconducting period, transistor 1 would have a voltage of 24 volts between emitter and collector.

In addition, there is a certain amount of ringing and overshoot at the instant the transistor is cut off. Thus the waveform, instead of being the absolutely square wave we saw in Fig. 3, actually resembles Fig. 4. This initial pulse peak can be as much as 20 per cent or 30 per cent of the amplitude of the square wave itself. By changing the bias on the base, by bypassing, or by changing the load, this pulse can be reduced. However, all these methods will give a round corner to the square wave pulse and also tend to decrease the steepness of the wave front. Any departure from the vertical in the wave front means a decrease of efficiency and increased wattage dissipated in the transistor itself, with loss



Fig. 3 - Square waveform.

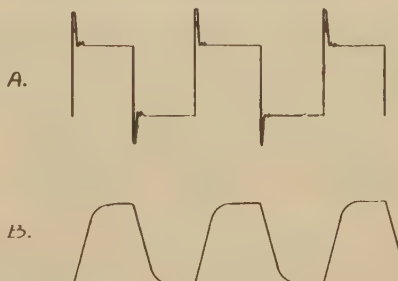


Fig. 4 - Waveforms.

of circuit efficiency and increased transistor heating. Therefore, this initial spike can be reduced by proper selection of bias and transformer parameters, but its complete elimination usually results in other and more undesirable faults.

This is all leading to a specific application -- railroads. The nominal standard voltage on diesel locomotives is 72 volts dc. Equipment designed for railroad application is expected to operate over a range of input voltage from 64 volts to 84 volts, and in the not too infrequent cases of faulty regulators, the voltage can rise to as high as 90 volts. When we double that and add the spike to get a figure for the voltage that would appear across the transistor in a railroad application, we find the voltage to be over 200 volts. As I mentioned before, the highest standard collector voltage rating for transistors is 100 volts and the more typical one is 80 volts. This creates a serious problem. With the present state of the art, a simple switching circuit cannot be hooked directly to the railroad input voltage.

One way out of this difficulty is shown in Fig. 5. Here the higher varied railroad voltages are reduced through a voltage regulator to a lower value that can be handled by the transistor switching circuit. This leads to a few difficulties, among them being that the transistors are still operating at collector voltages which are close to their maximum ratings, assuming that the switching spikes have been reduced. This reduction of switching spikes may cause heating of the transistors. The drop through the voltage regulator is direct loss.

The matter of considerably reduced efficiency is not of particular importance on railroads. The available current is of the order of 3,000 amperes,

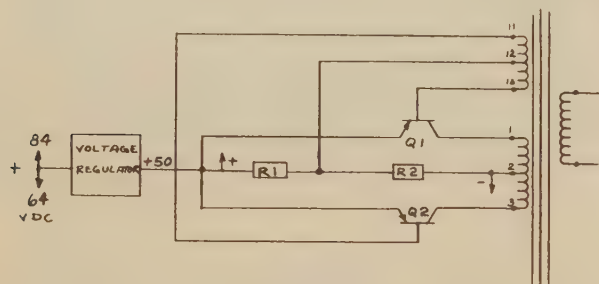


Fig. 5 - Switching circuit -- regulated input.

and whether the radio uses 2, 4, or 10 makes very little difference. However, the power dissipated in the voltage regulator is in the form of heat of up to 100 watts, this being dissipated either adjacent to or within the radio housing. Heat and transistors don't mix. Even these higher temperature units will fail at 95°C. Both these defects would contribute to transistor failure.

Another source of difficulty, not previously mentioned, is the existence of transients or other pulses on the power source. These can be filtered

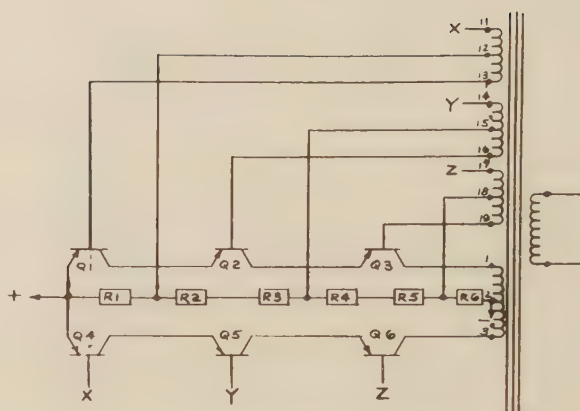


Fig. 6 - Series transistor switching.

in part at the input to the power supply, but they do present another cause of transistor failure, particularly if the transistors are already operating at close to their maximum collector voltage.

An unsuccessful method of solving this problem is shown in Fig. 6. In this, I attempted to place switching transistors in series so that the voltage appearing across any transistor would be only a portion of that appearing across the entire circuit. After many circuit changes, and many burned out transistors, I finally found out why this particular circuit would not work.

When the transistors are in the conducting half cycle, the voltage from collector to emitter is extremely low. The high, dangerous, square wave voltage appearing from collector to emitter is present when the transistor is cut off. No matter what biasing connections or systems we used, there was always some small amount of leakage current in T1 and T2. This small current was drawn through transistor T3 in its cutoff condition when it presented a high impedance. The result was a high volt drop between the collector and emitter of T3 of approximately two thirds to three fourths of the total amplitude of the square wave itself. The voltages across T2 and T1 were correspondingly smaller.

Additional series transistors did not help. Other methods such as shunting transistor T3 by low resistances or capacitance either loaded down the entire circuit, decreasing efficiency and causing heating, or distorted the waveform so that, although the distribution was equal between T1, T2, and T3, the waves were no longer square but had sharp peaks which exceeded in value the original square wave across T3. Other methods were tried including the use of separate switching circuits on separate cores, these circuits being connected in series.

The circuit shown in Fig. 7 gave immediate and beautiful results, solving all the problems of the methods previously discussed. Here we have all the standard switching circuits connected to the same transformer core, each complete in itself but wired in series with the other two. On starting, whichever of the six transistors conducts the

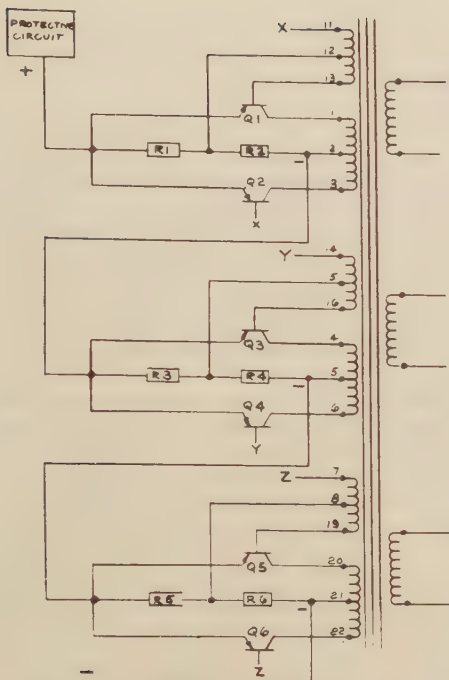


Fig. 7 - Sperry transistor power supply.

most turns on the other two which are wired in the same phase and cuts off the other three transistors. When the core saturates, one of the three cutoff transistors will take over, pulling the other two with it. Since the flux is common throughout, one transistor of each pair will fire at exactly the same instant and be cut off at exactly the same instant. The input voltage is divided almost exactly equally between the three circuits.

Now, if the input voltage is as much as 90 volts, the voltage across any single switching circuit is only 30 volts, and the collector to emitter voltage on a nonconducting transistor is 60 volts. With this wide safety margin, the transistor switching circuits can be designed with some amount of spike to give a steep wave front and extremely efficient transistor operation. The power supply efficiency remains high at any input voltage. The wattage dissipated in the transistors themselves is so low that in our large unit

we use no special heat sinks or radiating fins, but mount the transistors directly on the chassis.

The number of switching circuits wired in series on this common core depend upon the source voltage and the voltage rating of the transistors themselves. We are using transistors which have a puncture rating of 80 volts. Two such switching circuits in series using transistors with 100 volt collector ratings could be used. In this case, the margin of safety would be very much reduced.

From an economic viewpoint, 100 volt transistors are still quite expensive, whereas manufacturers have offered several power transistors with 80 volt ratings at considerably reduced prices. One of the big advantages of transistor power supplies over rotary or vibrator types is in reduced maintenance. We like to keep a good healthy safety factor to maintain this advantage.

To insure high switching efficiency, all the transistors are forward biased. This means that the current through the conducting transistors is limited only by the back emf of the transformer winding. In case of any failure of the transformer itself or even something like a shorted secondary winding which considerably reduces the inductance of the primary windings, the current flow through the transistor would be limited only by IR drop through the transistor itself and its half of the primary winding. Since both these resistances are quite low, the transistor would burn out due to excessive current.

All the means by which I have tried to reduce this current load during power supply failure, such as self biasing or limiting resistors, have resulted in decreased efficiency during normal operation. Fuses are also ineffectual. In the case of a sudden failure, the current increase in transistor burn-out occurs much faster than the blowing of the fuse. This has been solved as well by the use of a sensing circuit which turns off the incoming power at the instant of switching circuit failure.

In summary, the stacked transistor switching circuit is all we ask it to be. It is lightweight, extremely efficient, requires very little maintenance, and can be used for any reasonable input voltage merely by varying the number of series switching circuits.

THE USE OF MINIATURE TUBES IN CLASS C CIRCUITS

A. Dzik
Radio Corporation of America
Harrison, New Jersey

Summary -- Receiving-type tubes designed primarily for small-signal class A applications are being used in an increasing number of class C circuits in mobile transmitters and other revenue bearing industrial equipment requiring a high degree of reliability. Tube performance in such circuits is often limited by the effects of class C operation on the individual elements of the tubes. This paper analyzes such effects in the RCA 7054, a miniature sharp-cutoff pentode designed for use as a low-level frequency multiplier in mobile service, and describes circuit-design techniques which can be used to improve equipment reliability.

Cathode-Current Requirements

The maximum electron current which a cathode can provide at its normal operating temperature is known as "saturation current." This value is usually measured at the point on the plate-characteristics curve beyond which the current fails to increase proportionally to the three-halves power of the applied plate voltage. The saturation current for oxide-coated cathodes, expressed in terms of emission per unit area, is about 0.3 ampere per square centimeter of emitting surface. Some references give saturation-current values up to 2.5 amperes per square centimeter. However, these higher values are obtained in tubes under ideal laboratory processing and not in ordinary mass production technique.

Because relatively large variations of surface quality are produced during the

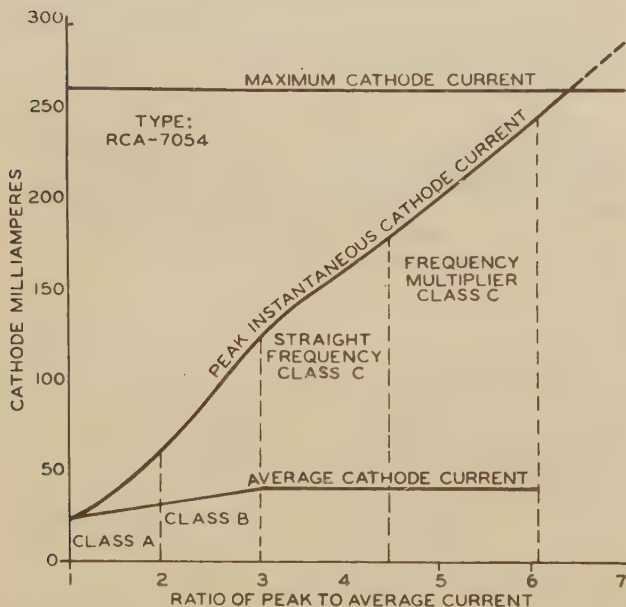


Fig. 1

sintering and activation processes, oxide-coated cathodes are usually designed for considerably higher emission capabilities than required. The emitter oxides are essentially semiconductors, however, and appear to be subject to transitory depletion-layer phenomena. Excessive peak or average currents may, therefore, cause permanent damage to the emissive coating.

The ratio of peak instantaneous cathode current to average current in a class A amplifier is about 1.5 or 2 to 1. This ratio increases to 3 to 1 in class B applications, and to 3.1 to 4.5 to 1 in class C circuits. In frequency-multiplier circuits, it ranges from 4.6 to 1 to 6.4 to 1. These higher peak-current requirements, illustrated in Figure 1, must be considered when receiving-type tubes are used in class C circuits.

The peak emission capability of the 7054, which has a cathode surface area of 0.88 square centimeter, is about 260 milliamperes. At typical class A operating conditions, this tube has a dc plate current of 19 milliamperes and a dc screen-grid current of 3.5 milliamperes, or a total cathode current of 22.5 milliamperes. The peak cathode current, based on the ratios given above, is between 33.5 and 45 milliamperes, or well below the maximum emission capability.

When this tube is used in class C application, the average cathode current could be as high as 80 milliamperes except for the limiting effect of the control-grid and screen-grid dissipation rating; the average current is limited by these ratings to 40 milliamperes. The peak current, again based on the ratios given above, is then between 124 and 180 milliamperes under normal class C conditions, and between 184 and 244 milliamperes in frequency-multiplier circuits. Although these values are still within the calculated peak emission capability of 260 milliamperes, the repeated surge of such large currents may often damage the cathode coating and impair tube performance.

When tubes are not specifically rated for class C or frequency-multiplier operation, special precautions must be taken to keep peak currents below the maximum capabilities of the cathode. Consideration should also be given to the effects on cathode currents of variations in heater-supply voltage which occur in mobile equipment and certain other applications.

Heater Voltage

Operation of the heater over a wide range of supply voltages introduces several deleterious effects. Increased heater power raises

the cathode temperature and accelerates the sublimation of cathode impurities. Cathode materials may deposit on the internal structure of the tube, or on surfaces of the glass envelope or mica insulators. These deposits increase the tendency of other electrodes to become emitters during operation, especially at high temperatures, thus causing undesirable reverse currents. Such deposits also increase rf losses.

In addition, high heater voltage accelerates the migration of nickel from the cathode sleeve, causing the tungsten heater to become brittle and often causing premature heater failure due to fatigue under normal on-off switching. Deterioration of the heater insulating coating also increases heater-cathode leakage, and the resulting cathode poisoning may decrease emission to values insufficient for class A operation. Heater-cathode leakage and direct heater emission also increase both tube noise and rf losses.

Decreased heater power, on the other hand, may cause the cathode temperature to drop below recommended values. It may then be difficult to maintain the required peak currents, and "sparking" may result if the emission becomes confined to localized spots of high current density on the cathode. Low-temperature operation also increases poisoning of the cathode due to gas absorption.

Heater circuits should be designed to keep supply-voltage variations within the tube ratings (usually ± 10 per cent for receiving-type tube and approximately ± 20 per cent for RCA mobile-line tubes). If larger supply-voltage variations are unavoidable, heater-voltage regulators should be employed. Whenever possible, heaters should be operated at reduced voltages during "standby" periods to minimize switching surges.

Series connection of heaters should be avoided because they introduce additional voltage variations on individual tubes. If series connections are necessary, a bleeder network should be used across each heater to reduce surge voltages and to minimize the effect of variations in heater warm-up time. The use of a series resistor to carry 15 per cent of the load also helps to increase reliability.

Control-Grid Currents

In receiving-type tubes, the control grid (grid No.1) is usually placed close to the cathode to provide a high transconductance. This structure is satisfactory for class A applications because the control grid is negative with respect to the cathode and draws no current. In class C circuits, however, the control grid is driven positive and draws current and, therefore, dissipates power. This power dissipation, combined with the proximity of the control grid to the cathode, may

flows through the resistance in a direction opposite to that of the direct grid current, as shown in Figure 2. This reverse current thus reduces the bias voltage and increases plate cause the grid to act as an emitter at fairly low levels of grid drive.

Because relatively high bias voltages are required in class C circuits, the major portion of the bias is usually obtained as the product of direct control-grid current and grid-circuit resistance. Control-grid emission, however, produces a reverse grid current which

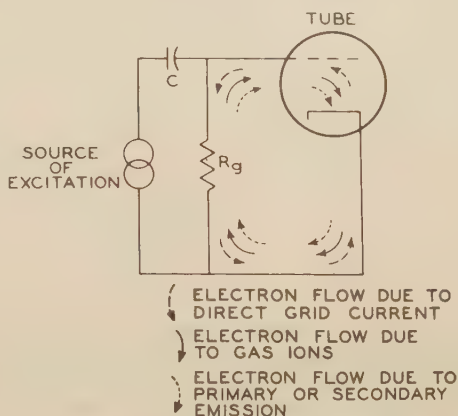


Fig. 2

current and dissipation. The increased operating level of the tube, in turn, produces increased grid emission, which further reduces the bias, and a "runaway" condition results.

The presence of gas ions in the tube may also cause reverse current to flow in the grid circuit, as shown in Figure 2, again reducing the bias voltage and producing a "runaway" condition. In addition, the gas current flowing to the cathode may poison the cathode coating and reduce emission capabilities.

The effects of reverse control-grid current may be minimized by the use of some cathode-resistor bias. The value of the resistor should be chosen to protect the tube and components in case of loss of excitation. Care should be taken to allow for zero bias dissipation in the cathode resistor, and to protect service personnel from high positive potentials which may exist on other circuit components if the cathode resistor opens.

The dc resistance used in the control-grid circuit should be as low as practical with the available grid drive. A low resistance reduces the effects of both leakage and reverse control-grid currents.

Screen-Grid Characteristics

The screen-grid (grid No.2) current of multigrid tubes rises sharply in the low-plate-voltage region because the screen grid, having a higher potential than the plate, attracts a

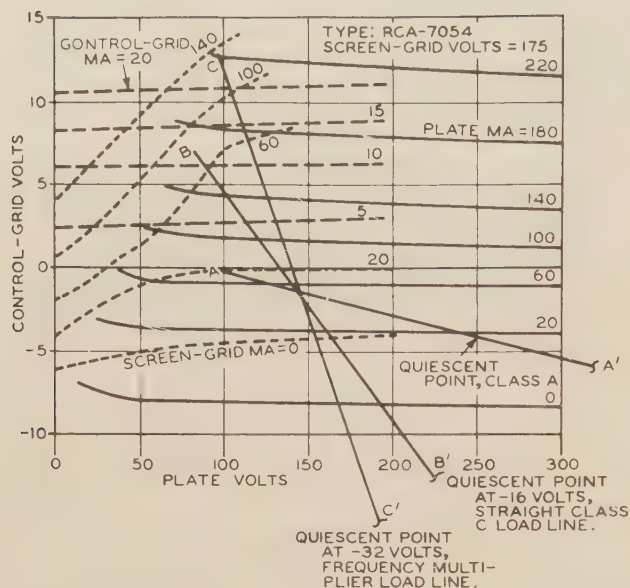


Fig. 3

larger portion of the cathode current. Provided adequate rf bypassing is used, the screen-grid dissipation is equal to the dc input power, or is a function of the screen-grid current at fixed screen-grid voltage.

In small-signal applications, the ratio between plate and screen-grid currents remains relatively constant with changes in control-grid voltage. Even the furthest excursion of the class A load line (at the zero-bias line, as shown in Figure 3) is well below the sharp rise in the screen-grid current characteristic.

In class C or frequency-multiplier operation, however, the control grid may be driven into the positive region at low plate voltages, as shown in Figure 3. Under such conditions, the sharply rising screen-grid current and dissipation actually limit the amount of available plate current. The class C and frequency-multiplier load lines are redrawn in Figure 4 as dynamic characteristics, with plate, screen-grid, and control-grid currents shown separately. The rapid rise in screen-grid current and the limiting effect on available plate current are more apparent at higher positive control-grid voltages.

Care must be used in choosing the load line for class C applications to keep the screen-grid dissipation within its maximum rating. It is also desirable to place a resistor in series with the screen-grid supply to compensate for variations in screen-grid current during life. As mentioned above, adequate bypassing should also be used to insure good ac regulation.

Suppressor-Grid Considerations

Because the suppressor grid (grid No. 3) of a receiving-type tube normally operates at

zero or negative potential, suppressor-grid current is negligible and suppressor-grid dissipation may be ignored. It should be mentioned, however, that the actual peak rf voltage in the plate circuit is often as much as 1.5 times the dc plate voltage in fm or cw class C circuits, and is approximately 2.7 times the dc value for 100-per-cent plate modulation. Under these conditions, the plate-to-suppressor-grid breakdown voltage may be exceeded, and destruction of the suppressor grid may result.

Plate Dissipation

In class A applications, only 20 to 30 percent of the dc input power is delivered to the following stage under maximum-signal conditions. In some cases, the power output is even further limited because of distortion considerations. Consequently, the quiescent operating point should be chosen so that the product of the plate voltage times the plate current is not greater than the maximum plate dissipation at zero signal.

In class C operation, however, it is possible to obtain a practical power conversion efficiency of 65 to 85 per cent, within the frequency limitations of the tube. The dc input power, therefore, is determined by the rf conversion efficiency of the tube, as well as its maximum plate dissipation.

Typical class A operating data for the 7054 show a dc plate voltage of 250 volts and a dc plate current of 19 milliamperes, or a product of 4.75 watts. The maximum plate dissipation for this tube is 5 watts. If an efficiency of 75 per cent is obtained in class C circuits, a plate power input 20 watts may be used without exceeding the dissipation rating.

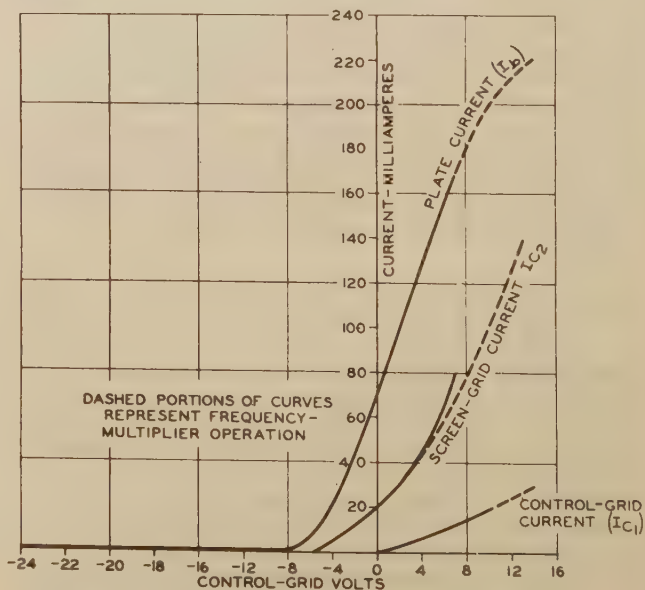


Fig. 4

For a plate voltage of 250 volts, however, the plate current would have to be 80 milliamperes, or twice the recommended maximum dc cathode current, to provide an input of 20 watts. For the recommended plate current of 40 milliamperes at a plate voltage of 250 volts, the dc power input is 10 watts. At a conversion efficiency of 75 per cent, the output power is 7.5 watts, and the plate dissipation only 2.5 watts. The limiting factor in class C applications, therefore, may not be the plate-dissipation rating, but the emission capabilities of the cathode.

In summary, where tubes were not specifically designed for class C of frequency multiplier operation, their effective reliability can be enhanced by observing the following precautions:

- a) Operating within the available peak cathode currents
- b) Proper choice of loadline to keep within the limits of screen grid dissipation
- c) Making allowance in the heater voltage variations as it relates to the internal temperature of the tube elements.

APPLICATION OF VEHICULAR COMMUNICATIONS TO RAILROADS

L. R. Thomas
The Atchison, Topeka, and Santa Fe Railway Company
Chicago, Illinois

Over the years, there have been several papers given regarding the type of equipment used in railroad communications, as well as how radio is used by the railroads. It is my intention to touch briefly on the description of the use of radio and stress the problems of installation and maintenance of vehicular communications on railroads.

These problems are brought about by the fact the railroad operation is scattered out on a ribbon-like area over long distances, and, therefore, the maintenance of the railroad vehicular communication plant presents a unique and often difficult problem as compared to the use of vehicular communications in some other services.

In the years prior to 1944, there had been some experimentation with the use of radio on railroads. Due to the frequency which was used for these tests combined with the fact that there were no frequencies definitely assigned for the railroad's use, there was little interest shown by the railroad managements in radio operation.

In 1944, after the second World War, the frequency spectrum in the vicinity of 160 megacycles was opened up, and equipment that would operate satisfactorily in this range was beginning to be available. At this time, the use of radio was again brought up, and extensive tests made by various railroads over the country indicated that this frequency range along with equipment which was being developed would be entirely practical for installation on railroads. Early tests with World War II equipment that had been used in aircraft indicated that this type of equipment could not stand the shock and vibration in railroad service, and, therefore, equipment which was more rugged and of a different construction would have to be developed to make the use of radio practical.

The Railroad Radio Service was established in 1945 by the FCC, and from that time on, the railroads have been applying radio at a steadily increasing rate. The first installations in some cases were made in Yard and Terminal operation since the greatest economy could frequently be obtained in that service. Other roads progressed their installation on the

basis of providing communication between the locomotive and the caboose since it was definitely developed that this type of operation would speed up the movement of trains over the railroad as well as contribute to the overall safety of operation of these trains.

Vehicular communication as applied to the railroad is divided into two basic types of service:

1. TRAIN SERVICE which is used to provide communication between the locomotive and the caboose of freight trains, between the locomotive of a passenger train and packets used by the train crew, between trains, between way side station and trains, between railroad personnel on the ground with packets and the locomotives or cabooses, and between the locomotive and cabooses and automobiles, trucks, or other vehicles that are used in connection with the movement of trains from one point to another. Train service also would include use of radio on work equipment along the right-of-way of the railroad. This work equipment consists of mechanized ballisters and other heavy track equipment.

2. The second category is YARD AND TERMINAL which provides for communication in the terminal area between Yardmasters or Assistant Trainmasters and switch locomotives in industrial areas, in Yards between the Yardmaster and the local switch locomotives, between personnel on the ground with packets and the Yardmaster, or clerical employees. The Mechanical Departments Car Inspectors use packets and mobile repeater stations to permit communication over the entire Yard or Terminal area.

The radio in these services has been found to be capable of improving the efficiency of the operation, thereby increasing the economy and at the same time contributing to the safety of railroad operation.

We in the railroad communications field experienced some rather difficult years in the early use of radio in that our managements frequently asked why we could not use the same radio equipment on trains that was used in automobiles. One of the reasons why this question continuously arose was the fact that the installation on automobiles was much less

expensive than the installations on railroad rolling stock.

To give you an idea of the comparison an installation of VHF radio on an automobile where a larger generator was not installed cost approximately \$600. The installation of radio equipment on the Diesel locomotive cost in the vicinity of \$1500. By the same token, an installation of radio including a suitable axle driven power supply on cabooses run in the neighborhood of \$2,500 and in some cases higher.

In the case of vehicular communications for, let's say a taxicab company or a similar operation, the cost of the base station was not too excessive in that normally an antenna of reasonable height could be obtained by an installation on top of the building that houses the operation or by use of a tower or pole adjacent to such buildings. Frequently where train base stations are installed out along the right-of-way there are neither buildings nor power available. These stations must be controlled from a point from 2 or 3 miles to 50 miles away by an operator at the first open telegraph office. Since it is necessary to provide buildings, towers, power, and control circuits, the expense of the installation of the railroad base station is very high as compared to other services. As you all know, it is rather difficult for the man who is not familiar with the way VHF radio operates to understand why he cannot put an antenna on a roof of a low building at the point where the operator is located and talk for 50 or 100 miles without difficulty. This is particularly true since some of the early installations in other services were in the 35 to 50 megacycle band and could naturally cover greater distances from a given installation.

I have indicated that the cost of installation on railroad rolling stock is high, and you, no doubt, wonder why a figure of approximately \$1,500 should be necessary for the installation. As an explanation of this, let me go back a few years and say that our first radio equipment on railroads was of 3-unit construction--transmitter, receiver, and high voltage power supply as separate units mounted into a single plug-in rack on the railroad rolling stock. This 3-unit construction is basically more expensive than single unit construction used in automobiles and contributes to increased cost. Approximately 4 years ago, Committee No. 4 of the Association of American Railroads established standards for a single package unit which has helped to reduce the overall cost of installation.

The equipment used by the railroads must be more rugged than necessary for most other services, for example, we use a rugged antenna on top of the rolling stock so that an employee can grab it if necessary, and the unit will support his weight. This antenna provides a better radiation pattern than the normal whip, but it also costs more. On the automobile, you have a small speaker which is used primarily for calling purposes, and the quality of reproduction of this speaker is poor. The speaker itself is inside the car, protected from weather and dirt, and, therefore, need not be of as rugged construction. On the railroad we must have speakers that are weather-proof, since they are used under conditions of dust and moisture, therefore, are a more expensive and reliable type unit. The control unit and the handset also have to stand more rugged service, and must provide for operation under conditions of dust and moisture, therefore, are more ruggedly built than the units used in automobiles.

Now we come to the fact that the automobile has a 6 or 12 volt battery and power for the radio equipment can readily be provided. In the case of the railroad locomotive, the battery is normally 64 volts provided by a group of wet cells which have a peak charging condition of approximately 80 to 84 volts and a minimum battery operation in the neighborhood of 58 to 60 volts. Due to this wide range of voltages, we design equipment around a 72-volt center. Up until the time the transistor became available, we had to install a separate rotary converter or a vibrator converter to change the direct current 64 volt battery into 117 volt 60 cycle AC power for use of the radio equipment. These alternators or vibrator inverters increase the cost of installation from \$300 to \$500. Now that the transistor is available, we have transistor power supplies which will operate directly from the nominal 72 volt supply. Unfortunately, the cost of these transistor power supplies is approximately the same as the present cost for a vibrator inverter plus the high voltage power supply. The present cost of the vibrator inverter is approximately \$225, and strangely enough the 72 volt transistorized power supply on the radio equipment has increased the price of that equipment approximately \$200 to \$250. Therefore, we are in the same condition price-wise as we were before. There is one decided advantage; we do not have the alternator or vibrator equipment to maintain, therefore, our overall maintenance costs are reduced, and since the transistor is a more reliable

unit than the vibrator, our service availability is increased.

Now let's talk for a moment about the caboose installation. The average railroad caboose has no power available. Kerosene lights are used for the markers and quite frequently a Coleman or similar type lamp is used for lighting the caboose. In recent years, power has been installed and lights provided at the time the radio installation is made. The installation of power on cabooses has become more or less standardized on the basis of a 12-volt unit with the cost varying from approximately \$1,200 to \$1,300 to as high as \$3,000 according to the type of axle driven equipment and batteries which are used. You can readily see that this plus the cost of the radio equipment makes an installation on a caboose several times more expensive than the installation in an automobile.

Up to now, I have talked about the cost of installation of equipment on locomotives and cabooses. Let's talk for a moment about the use of paksets in railroad service as compared to the use of paksets in other vehicular service.

For example, if paksets are used by a police force, the officer using the set understands that if he cannot establish communication in one spot he can go to the top of a hill or some other high spot, and there he can talk into his central point without difficulty. In railroad operation, we expect these paksets to talk, not only from flat ground, but in between strings of railroad cars, from one end of the Yard to the other, distances of 1 to 4 or 5 miles. As you no doubt know, the present 1 watt pakset will not normally talk from one pakset to the other over flat terrain for distances of 2 to 5 miles. We add strings of steel railroad cars plus the fact that there are curved tracks in the Yards which completely block line of sight transmission, and it can be readily seen that the pakset will not provide the type of operation which is necessary for reliable communication. In order to overcome this, we must add mobile repeater stations at a central point in the yard area to make it possible for 1 pakset to carry on satisfactory communication with the other. Here again we go on the high side of the cost of operation.

This gives you some idea of the problem of costs in railroad use of radio. Now let me give you a few of the problems encountered in the maintenance of equipment. Speaking of the Santa Fe's

operation with which I am thoroughly familiar, it is not uncommon to run a locomotive in freight service from Barstow, California, to Argentine, Kansas, a distance of approximately 1,632 miles. Now it can readily be seen that it would be rather impractical for one radio shop to try to keep track of and maintain the radio on this locomotive with the possibility of it being 816 miles from the center of the operation or 1,632 miles away from either end. This means that we must have radio shops distributed along the right-of-way to take care of the overall maintenance. Unfortunately, as the locomotive progresses over the railroad, it does not stop for any length of time in the terminals. Therefore, plug-in units must be used, and some one must be available to change out these units in a very short period of time to provide continuous operation. We have not reached the point as yet where a locomotive, caboose, or other rolling equipment will be held from service because of radio failure.

It is not uncommon for a radio set to fail departing one terminal and travel a distance of from 100 to 300 miles before there is anyone available to make repairs. Since the time in terminal is short, notice of failure of the radio equipment must be received sufficiently in advance of the train's arrival so that personnel can be available to change out the defective units without delaying the train. Since we cannot delay trains to make repairs to radio equipment, we must of necessity establish a program of preventative maintenance which will enable us to anticipate the failure of equipment. Under such a program, the units are removed from the rolling stock on a regular basis and run through a repair shop for a thorough check and returned to service.

In order to maintain communication with the trains for the length of the railroad, it is necessary that base stations be installed along the right-of-way at locations that will provide overlapping coverage from one station to the other. It is necessary that the outlying stations which are not located at points where personnel is on duty be remotely controlled from open offices. The maintenance of these stations is difficult in that they are at outlying points, frequently on mountain tops or other locations, that require 2 to 4 hours driving time to get to the station to perform maintenance. In order to keep service as reliable as possible, we normally provide a fall back set of equipment

which can be placed in service from the control point in the event of failure of the primary unit. In cases where the radio stations are installed on mountain tops, they are usually remotely controlled by a radio link from the nearest open office. In cases of this nature, tone equipment is used to switch from one defective piece of equipment to the other. For example, if the receiver on the control link on the mountain top fails, it is frequently possible for the transmitter at the telegraph office to be switched to the frequency of the train station on the mountain and through its receiver, using tones, cut in the spare control link receiver which will restore operation. By the same token, if the receiver or transmitter of the primary train station fails, the spare equipment can be switched into service by means of tones on the radio link.

I have touched on some of the basic problems of radio installation on the railroads as well as having given you an idea of the types of service in which the radio is used. I have not mentioned the fact that our use of radio on the railroads is continually growing. By that I mean we are continually finding new uses for radio which increase the overall speed of operation, improve efficiency, and quite frequently contribute to safety. As previously pointed out, the basic train service installation is from end-to-end of freight trains, between trains, from the locomotives of passenger trains to their crew by pakset or to the base stations along the right-of-way, but I have not as yet mentioned the fact that we are now beginning to use radio in connection with the maintenance of way equipment. Such equipment in railroad terminology includes large machines which automatically change out ties, and machines which are used to tamp ballast under the ties to make a reliable road bed. There are numerous other large pieces of equipment that operate on the track, a few of which include ballast regulators that scarify and regulate the ballast along the road bed shoulders and units which burn or chemically treat weeds. When trains pass over the area in which work is being done, provisions must be made to move these large units of equipment in the clear of the main line to let the trains pass over the tracks on which the equipment was being used. On some railroads, radio is installed on these units so that the personnel operating the equipment can be notified of the approach of a train as it is en route. This gives them ample time to move the work equipment off the main line and to

notify the train crew that the track is clear and that they may proceed over that section of the railroad. On railroads where radio is not used for this type of service, a flagman must be provided on each side of the track gang and a lineup is furnished which provides information regarding the time of arrival of trains. Presently some machines are operated by train orders which set out definite time for their work on the track and definite times when the units will be in a siding for trains to pass. On railroads where radios are provided for the purpose of controlling train movement over the areas where maintenance work is being performed, the maximum time can be spent on such work and at the same time avoid train delay. It can readily be seen that the use of radio in this type of service will speed up the operation. This is one of the many different and unique types of services that we are developing as we continue to find more and more uses for radio.

In speaking about the future use of radio by the railroads, it is easy to visualize microwave systems along the right-of-way which will provide basic communication for general operation. The same microwave system will provide control circuits for VHF radio for communication with the trains.

This VHF communication will enable us to keep in constant contact with the trains as they progress over the railroad. We will be able to keep in contact with work equipment on a separate frequency from the point-to-train frequency, thereby increasing the efficiency of maintenance of the railroad plant. In connection with future use, it is also foreseeable that all trains will be equipped with standard 25 or 30 watt units on the cabooses and locomotives, plus paksets for the head and rear brakeman so that they can communicate with the caboose or locomotive when they are inspecting the train or picking up and setting out cars. Paksets will be provided to our maintenance of way forces for operation along the right-of-way.

As I see it, the future of railroad radio is bright. However, we must take into consideration that the use of radio by the railroads is something that has to prove itself and that it is not a plaything or a gadget that can be used indiscriminately. We also have to consider that the use of radio by the railroads is not a jackpot payoff like it often is for taxicabs and other mobile services. Taking this

into consideration, the installation of radio will be a gradual, slow progression which will develop on a stable basis. Those of you here who are in the manufacturing business should realize that the railroads must have stable, more reliable equipment in order to extend the service so that the units can progress from one territory to the other over long distances with a minimum of failure between terminals. You should also realize that this is not a flash-in-the-pan proposition but is a steady, reliable type of service which might be classed as a "bread and butter" type of operation where the installations will eventually reach saturation and fall into the replacement category. There will be sufficient railroad installations in service so that sets will be continually in the process of replacement with newer and more reliable equipment. It is my hope that the use of transistors in the receiver and part of the transmitter circuits will increase the reliability of operation and substantially reduce the number of failures as well as reduce battery drain and make the overall problem less difficult.

It is also my hope that in time the transistors which are used will bring about a price reduction instead of the continuous price rise which has been the pattern over the past years. The use of radio of the radar type for speed indicating devices and for measuring the rollability of cars in humping yards is increasing and will be an important factor as railroads modernize their yards. There is an open field for the use of hotbox detectors along the right-of-way, and possibly in the future, there can be some type of a signal transmitted by radio from these locations to the train crew so that they will know when a hotbox has been detected and can take immediate action to correct the situation.

With the prediction that radio in the form of vehicular communication will be a continually expanding operation in railroad service and that we are in the vehicular communication field to stay, I will close my comments with the expressed hope that the reliability of the equipment will increase, that the price will decrease.

SELECTIVE SIGNALING IN THE BELL SYSTEM - RELAY TO TRANSISTOR

W. G. Chaney
American Telephone and Telegraph Company
New York City

Summary

Selective Signaling is used in Domestic Public Land Mobile Systems by many Telephone Companies to individually call vehicles equipped for mobile telephone service. Problems of reliability, speed, simplicity and number capacity, rule out many possible systems. A mechanical device used successfully for the past years is now proving both bulky and costly so that newer devices are under consideration.

A description of the present day system is given in this paper inasmuch as any new equipment will be expected to perform in a compatible manner.

Introduction

Mobile telephone service differs from other applications of vehicular radio in many ways, one of which is that a greater degree of flexibility is required. The mobile telephone is not identified with any one base station. It is the subscriber's to take where he will from city to city, and in each place, it is always expected to work the same. The mobile telephone in fact, is designed to be a companion to the standard home telephone instrument.

Background

The development of mobile telephone service hinged on the practical solution to method of selective signaling. Recognizing the fact that multi-party service was inevitable because of channel limitations, a system to selectively ring desired cars was searched for. Because of the roaming nature of the service, more than just a 100 or so codes to cover the possible number of cars on a channel was required. Cars serviced in New York, could be expected to go to Philadelphia, Boston, Detroit, Pittsburgh, Chicago, Washington, in short, anywhere, and there should not be a duplication of numbers in these other cities. The actual total was somewhat alleviated in practice by the fact that certain customers might not be expected to roam. This allowed for a duplication of codes under some cases. From statistics, a goal of 10,000 separate codes was initially established. Other requirements then had to be met by the system.

One was the range over which reliable operation was assured. The relative relationship between signaling and talking ranges has long been argued. Ideally, it might be said that the two should coincide to insure that every time the car telephone bell rang, the parties could converse. From a practical point of view, since tone and speech ranges could not be made exactly

coincident, it seemed that signaling should out-distance talking by a reasonable margin. Inasmuch as a 12 db speech-to-noise ratio was considered to be the commercial talking limit, a 6 db tone-to-noise ratio was selected for signaling.

Fail-safe operation was required. That is, signaling errors due to transmission impairment should result in a loss of signal - not the false operation of another bell.

Finally, but not least important, factors such as size, weight, power, vibration, temperature effects and cost had to be considered.

66A Selector

At the time - this was about 1944, - one system was already in use which seemed to meet all of the basic requirements. This was the two-tone 600-1500 cycle signaling system. Although not originally designed for radio applications, it had been used with success in the coastal harbor radio service. Its origin began with wayside signaling on railroad right-of-way channels and similar wire line applications.

The heart of the device was a unique polar relay actuating a stepping mechanism that could be latched at discrete points along its travel. The relay is shown in Figure 1. It has been variously known as the Gill Selector, D 175279 Selector, 60-type Selector, 66A Selector, etc. In slightly modified forms it is in use in a number of applications.

The relay, in spite of its size, is made with about the precision of a pocket watch - and works with remarkable dependability. As a matter of interest, efforts made to reduce the size of the relay were not successful. As originally designed, it was just the proper combination of mass and size for satisfactory operation. The Gill Selector, designed about 1915 is to all intents and purposes identical with a 66A Selector made in 1958.

The two-tone system uses two audio frequencies, in this case 600 and 1500 cycles, to differentiate between the contact conditions of the dialing sequence. At the selector, two tuned circuits are provided to separate the audio signals. Each is rectified and the resulting current delivered to separate windings of a polar relay. These windings are so poled that 600 cycle tone will cause the relay to close in one direction and 1500 cycle tone will reverse its operation. A bias winding is switched by the relay action so that it holds in whatever operated position it was in last. The output

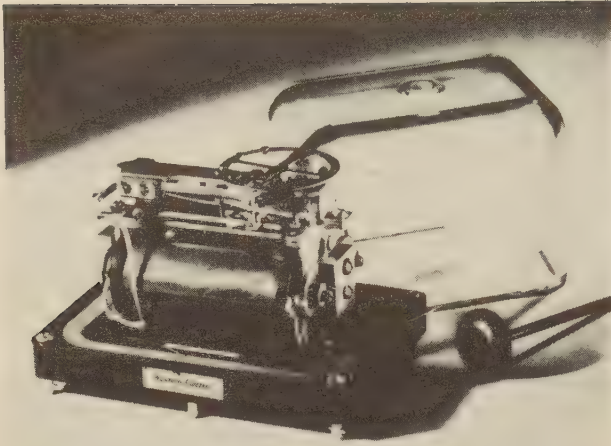


Fig. 1 - 66A selector relay with cover removed.

contact of this polar relay is in series with a capacitor and the winding of the Selector relay. This output contact is switched between battery and ground by the polar relay in the presence of audio tones. The transient charge and discharge current surges to the capacitor operate the Selector relay. Sustained tones or removal of tone allows the transient current to delay and the Selector relay will release.

The time constants are established so that the relay steps during dial pulses of about 100 milliseconds and releases during interdigit spaces of about 250 milliseconds or greater.

The relay operation sequence is as follows:

Application of current in the positive direction operates the polar relay armature to the right; negative current closes it to the left. With no current the armature assumes a neutral position. The armature is connected to a driving mechanism by proper linkage so that motion to either the right or left cause a pawl to engage a tooth of a stepping wheel and advance it one step. As long as the armature is held operated, the driving mechanism will hold the wheel in place. If the armature is reversed rapidly, the pawl will drop back, pick up a second tooth and advance the wheel one more position. Successive operations of the relay will step the wheel around continuously. If, however, current is removed and the armature assumes a neutral position, the pawl is disengaged and a holding arm brought into position. The stepping wheel has a number of holes along its outer edge into which small pins may be placed. If a pin is in the right position to engage the holding arm, the stepping wheel will lock in position during the time current is off. If there is no pin in the current hole, the stepping wheel will return to rest under power of a hair spring. A series of pulses corresponding to the number of a digit, step the wheel that many places. A pause corresponding to an interdigit space allows it to hold or drop back depending on whether or not a holding pin is in the correct

position. Sufficient stepping will close an electrical circuit between a contact on the wheel and a fixed contact. A permanent holding pin serves to lock the wheel at this point to maintain the output circuit. In practice, no two holding pins are used in adjacent locations; therefore, the digit one can always be used to advance the wheel one place and unlock any that might be latched. One is never used as a digit in a code.

To meet the requirements of this relay, a fixed procedure for selective signaling in the Bell System has evolved. The mobile service operator, in originating a call to a vehicle, plugs a switchboard cord into the mobile telephone line jack. As soon as a "Start Dial" lamp lights (indicating that the transmitter is on the air) she is ready to dial the car's five-digit number. At the control terminal, in the meantime, the transmitter has been turned on, 600-cycle tone is first applied to modulate the carrier and then after about 500 milliseconds, switched to the 1500-cycle tone. At this point, the "Start Dial" lamp is operated. The purpose of the first interchange from 600 to 1500 cycles is to create a digit 1 which clears all selectors and readies them to follow the ensuing dial pulses. When the operator begins to dial, each digit is represented by number of frequency shifts, 2 for 2, 3 for 3 and so on. Digits are sent at a frequency shift or pulse rate of 8-11 pps. In between digits, the last tone is carried over until the dial is again moved off normal. During this interdigit period, only those selectors having holding pins in the correct place hold. Others drop back to zero. At the end of the dialing, the terminal recognizes a 3 to 4 second idle interval and provides one final tone reversal to release all selectors including the one being rung before shutting off.

Coding

In an ideal system, 1/9 of the available codes could have the same first digit and thus lock up on the first digit. Of these 1/9 or only 1/81 of the total could have the same second number, another 1/9 or 1/729, the same third number, 1/6561, the same fourth number and 1/59,049, the same fifth number. Thus, if only one car is to be selected, 59,049 separate codes can be used. However, the mechanical arrangement used in the 66A Selector leads to ambiguity if all codes are used indiscriminately.

Codes totaling to 23 were selected for initial assignment. A specific total rather than random numbers was chosen for two reasons. One, it offered a means of error checking and two, it permitted a means of "all call" wherein a single pulse train would signal all cars. Both reasons have failed to materialize as any real advantage. However, the use of the 23 total was widespread. There are exactly 2030 combinations of five numbers out of nine from 2 to 0 that add to 23.

Once this choice was made and the numbers assigned, certain other combinations were ex-

cluded. For instance, given free choice, there are 2826 codes totaling 25. Of these, codes beginning and ending in 2 must be eliminated to avoid conflict with 23 pulse codes. This leaves only about 1950 unique codes.

The reason for eliminating 2's can be seen from the following:

25 pulse code	2 9 4 5 5	Car A
23 pulse code	4 5 4 5 5	Car B

When 2 is dialed, both selectors advance but only A holds. When 9 is dialed again, both selectors advance. This time both hold, one in 11 and one in 9. As the remaining three digits are dialed, the two selectors will both advance properly and both bells will ring. Increased demand on the number of code assignments have caused us to run through 23, 24, 25, 26 and into 27 digit series.

Other selectors to be described do not have this shortcoming and can realize a greater part of the full 59,000 codes.

Selector Assemblies

Western Electric receivers had the selector built in as an integral part. (Figure 2.) When a decision was made to utilize other than Western Electric receivers for mobile telephone service, a separate selector assembly was needed. This resulted in the 106A Selector Unit. It was a separately cased panel containing the 66A relay, tuned circuits, and three other relays necessary to make a complete selector. This was provided with new equipment until about 1956 and many are still in use. (Figure 3.)

Although the mechanical selector with two tone signaling is dependable, it has always had several shortcomings.

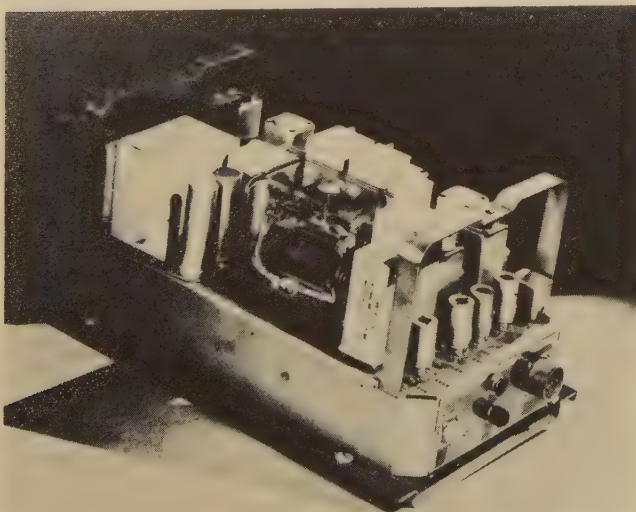


Fig. 2 - Western Electric 38A radio receiver showing 66A selector installed.

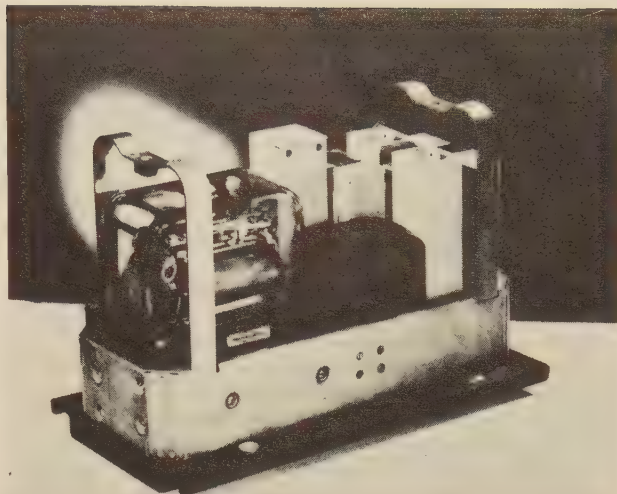


Fig. 3 - Western Electric 106A selector.

1. Channel holding time is longer than necessary.
2. Equipment is bulky.
3. Incremental cost is high.
4. It is subjected to mechanical limitation on orientation, vibration and shock.

In 1948, a trial of reed selective signaling was made on a Mobile Channel in Richmond, Virginia. This system was to provide more codes, operate faster and permit smaller, cheaper mobile set apparatus.

Each mobile set receiver was equipped with four vibrating reed selectors tuned to four different tone frequencies. The selectors were miniature, electrically driven tuning forks fitted out with contacts to close when the reeds were in vibration. With proper tones all four would be set in vibration simultaneously and a circuit operated to ring the bell in the car. The tones used were spaced 15 cps apart from 352.5 to 577.5 and 607.5 to 832.5 cps. All were odd harmonics of 7.5 cps, so that even order intermodulation products would not fall on usable frequencies. The reeds were sharply tuned, having an average bandwidth of 1.2 cps and required only about 1/2 milliwatt to close their contacts.

In order to get 10,000 codes with four reeds, a minimum of 24 tones are necessary if all combinations can be used. However, in such a system, the translation from telephone number digit to tone combination is rather involved. A simpler scheme is to use 40 tones in four groups of ten. One tone from each group is selected for each four-digit telephone number. Another system nearly as simple, involves only 30 tones. These are divided into two groups of 15, one group representing the first and second digits and the other group representing the third and fourth digits of the telephone number. Two tones of the 105 combination possible from each group were de-

signated to represent one of 100 number sets from 00 to 99. All four tones were then transmitted simultaneously.

The trial was considered completely satisfactory when certain tone combinations were avoided. However, the cost of the reeds and the tone generators outweighed the advantages and the project was abandoned. We should mention that Personal Signaling Service, now under development will use reeds.

Instead, the 106A Selector was redesigned to fit inside radio equipment cases. Except for some physical rearrangements, the only significant change was in the selection of components for a higher ambient temperature range. This unit, the Western Electric Company VS1 Selector (J41633A) was introduced about 1955. (Figure 4.) Even at this time, although selective two-tone ringers were built by RCA and Mackay Radio for shipboard use, we knew of no attempt by anyone other than Western Electric to design vehicular selectors. Multitone signaling, of course, was used by others for group or individual signaling in private radio systems.

Current and Future Development

In 1956, Canadian Marconi described a compatible system to the IRE PGVC National Meeting in Detroit. The system employs miniature thyatron in a counter circuit. In spite of the fact that the circuit is more complex than the mechanical selector, it does offer many advantages in size, weight and mounting arrangements. Although not in general use in the Bell System, the selector is considered equivalent in performance to the VS1.

By this time, three factors had been favoring the adoption of a new selector. One was the imminence of miniaturization techniques that promised to soon make the existing selector larger than the radio set. The second

was a downward drift in cost of the radio equipment. (Already the radio equipment cost only slightly more than the accessory items including selector.) And finally, a commercial equivalent was desired to meet non-Bell System needs.

One mechanical device on the market for a number of years showed some promise of potential size and cost reduction. This was a selector embodying the Secode or as it was then, the Electrical Communications Company 49HS Selector. As opposed to two-tone operation, this selector required the tone signal for a predetermined time, then stepped on the removal of tone. The number of base stations already in service and arranged for two-tone signaling made a non-compatible system seem uneconomical to the Bell System. However, by using special codes, a trial of the Secode unit working on a one-frequency basis was made in the San Francisco mobile system during part of 1957. Although the trial was considered successful, the relatively few codes available made the use of a single frequency selector impractical as a compatible device. Secode has since made available a compatible two-frequency selector under the code of RPD801.

Early in 1957, Scantlin Electronics, Incorporated demonstrated an all transistorized selector that would maintain complete compatibility. This seemed to show the most promise for miniaturization. If it fails to develop both the cost and size reduction that are ultimately required, other and possibly non-compatible systems will be investigated.

Among the devices or systems considered for non-compatible operation would include various reed signaling systems, a ring counter, shift registers, magnetic core devices or a stepping gas tube.

Conclusion

Mobile telephone service will be a growing communication means. Selective Signaling to make the most efficient use of party-line radio channels will be increasingly important.

References

Vibrating Reed Selectors for Mobile Radio Systems - A. C. Keller and L. G. Bostwich A.I.E.E. winter general meeting - January 31, February 4, 1949.

Vibrating Reed Selective Signaling System for Mobile Telephone Service-H. M. Pruden and D. F. Hoth. A.I.E.E. winter general meeting 1949.

Radio Technical Commission - Marine Special committee 40 Final Report.

A Selective Calling System to 106A Standards Employing Cold Cathode Thyratrons - W. Ornstein IRE Transactions - PGVC - 8, May 1957.

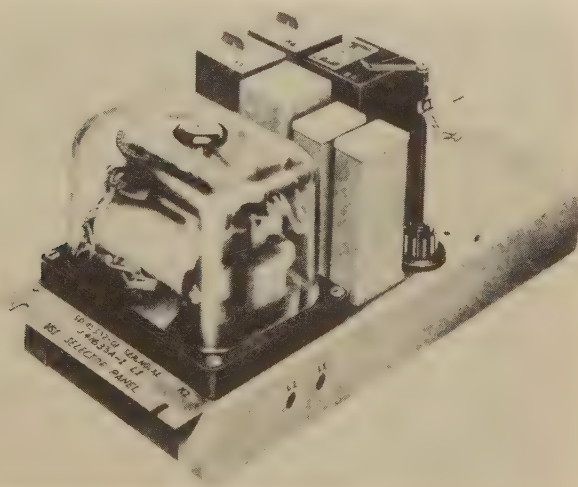


Fig. 4 - Western Electric VS1 selector.

A TRANSISTORIZED SELECTOR DEVICE
FOR BELL SYSTEM MOBILE TELEPHONE SERVICE

John R. Scantlin
Scantlin Electronics, Inc.
Los Angeles, Calif.

An all-electronic, fully transistorized selector device has been developed as a replacement for electromechanical selectors previously utilized in Bell System mobile telephone service. In addition to possessing greatly increased code capacity, the electronic selector can also function as the basic element of a fully automatic mobile dial telephone system.

Description

The SEI Model 1315 Selector is a device used in radio-telephone and other applications to enable selective calling of an individual station in a group of stations. It will accommodate over two and one-half billion different number combinations, and on a completely compatible basis with existing Bell System radio telephone installations will accommodate over three-quarter million subscribers.

The Selector performs the function of translating the standard Bell System mobile signaling code, which consists of two-tone audio-frequency signal shifts, into a switching action which operates a sound transducer and "call" light in the selected vehicle.

The Selector (figure 1) consists of a printed circuit board upon which are mounted twenty-four smaller removable

plug-in circuit cards. The overall dimensions of the Model 1315 Selector are 7-1/4" long by 4" wide by 1-7/8" high.

The unit weighs approximately eighty-seven ounces. The small circuit cards (figure 2) are 1-7/8" wide by 1-5/8" high and are completely interchangeable among Selectors. This plug-in feature makes maintenance--which otherwise would be a tedious and complicated process--a relatively simple matter.

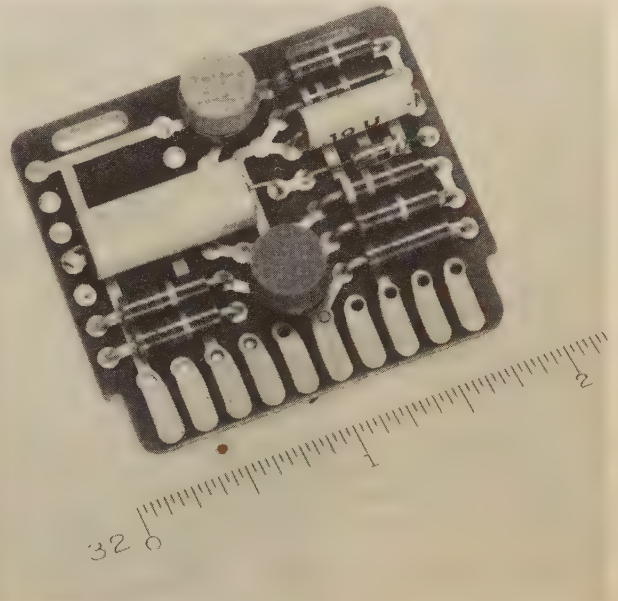


Fig. 2 - Typical circuit card.

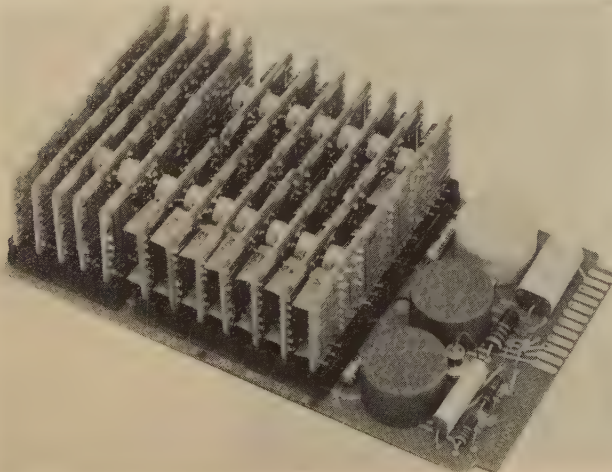


Fig. 1 - SEI Model 1315 selector.

The Selector is housed in an SEI Type 1315-J Junction Box (figure 3) which provides a means for interconnecting any standard commercially available radio set to the SEI Selector. For Bell System use, the Junction Box is connected with a Western Electric Type 47-E Control Unit and may be installed in a number of ways in the vehicle. Figure 4 illustrates a typical mounting arrangement in a late-model passenger car.

Operation

The Model 1315 Selector is completely compatible with existing Bell System installations and therefore is activated

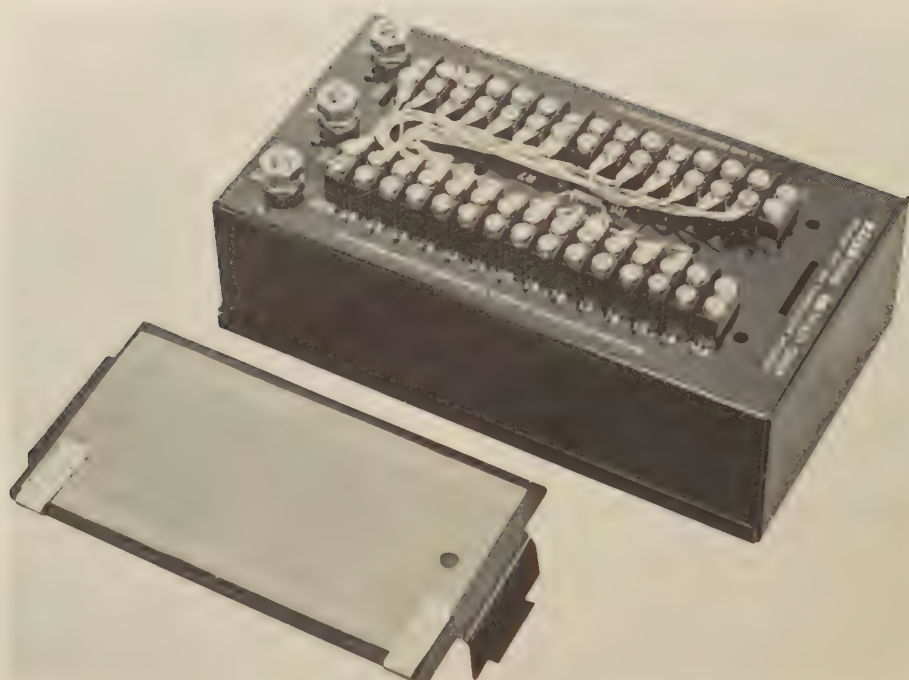


Fig. 3 - SEI Model 1315-J junction box.



Fig. 4 - Typical passenger car installation.

by a two-tone signaling code. It may be pointed out, however, that although the pulse repetition rate for Bell System signaling is from 8 to 11 pulses per second, the Model 1315 Selector, without modification, can accept pulses at rates up to 22 per second.

Using signaling techniques developed by SEI--which are, however, not compatible with present Bell System mobile telephone signaling--pulse rates of up to one thousand per second (on a voice circuit) may be accommodated. The 1,000-cycle pulse rate is a limitation imposed by the communication circuit rather than the Selector. The Selector itself can handle information at rates exceeding 25,000 pulses per second.

The design of the Model 1315 Selector is based upon SEI's digital selection/interrogation/identification systems. The key to the simplicity and economy of these systems lies in the encoding method utilized. Fortunately, the Bell System mobile signaling code is compatible with SEI's encoding techniques and therefore it was possible for the design of the Model 1315 Selector to utilize these same techniques.

The extreme economy and efficiency of the SEI system of encoding is indicated by the fact that the Selector designed for the Bell System, for example, has an ultimate capacity of over two billion, five hundred sixty-two million different codes and yet needs a storage capacity for only seven binary digits. Normally, a storage capacity of seven bits would result in a capacity of only 128 different codes.

The SEI system of encoding permits the breaking of the storage capacity of the Selector into two groups and interconnecting these groups in such a way that the effective capacity of the Selector is equal to the capacity of the first group raised to the power of the capacity of the second group. The difference between 128 and two and one-half billion codes clearly illustrates the effectiveness of this approach.

The Model 1315 Selector, which is fully transistorized, operates in the binary system. The Selector translates the Bell System two-tone signaling code into series of pulse groups representing the digits of the called number. The Selector then compares the incoming code with a permanent code stored in a resistor-diode memory.

When a mobile radio telephone station is equipped with a Model 1315 Selector, is in operation, and is dialed by the mobile service operator at the land station, five groups of alternate 600- and 1500-cycle tones are broadcast by the land station, are received by the mobile station receiver, and are fed to the Model 1315 Selector. Each frequency shift from 600 to 1500 cycles or from 1500 to 600 cycles generates a pulse in the Model 1315 Selector. In addition, pulses are generated representing inter-digit spaces. These pulses are stored, counted and compared against a code number which has previously been set up in the Selector memory by means of five small plug-in circuit cards. Upon receipt of the proper code number, a call light and sound transducer are activated.

Although at the present time the SEI Model 1315 Selector functions only as a Selector, the device contains circuitry, not used at the present time, which permits it to be used reciprocally as an identifier. Identification of the mobile subscriber is necessary in any practical automatic mobile dialing system, and must occur whenever the mobile customer wishes to dial a call.

Furthermore, it is necessary in any large scale automatic system to provide for automatic channel or trunk selection at the mobile unit. The Model 1315 Selector can also perform this function.

It is therefore possible to expand existing mobile telephone systems utilizing the Model 1315 Selector to fully automatic multi-channel dial systems, without creating obsolescence of existing installations.

A DIGITAL SELECTIVE SIGNALING SYSTEM FOR MOBILE RADIO

James H. Green and Jerry Gordon
Sylvania Electronic Systems
1100 Wehrle Drive
Buffalo, New York

Summary

A system for remote operation of a particular receiver selected from any number of similar receivers, all using a very narrow bandwidth, is described. Two tones that are turned on or off according to an address-determining binary sequence are transmitted to a group of receivers, one of which will recognize the address, or call, and activate a control circuit. A transistorized experimental model, small in size, with low power consumption, was built to prove the system.

System Theory

The purpose of a selective calling system is to notify one particular radio receiver in a group of many similar receivers that it is being, or has been, called by the transmitter that is associated with the system. The call signal used in the system to be described is a combination of carrier frequencies that occur according to the dictates of a binary sequence. Although the provision of selective calling is the main objective in this system, the technique can be applied to a variety of uses. For example, the call signal can be used to energize control circuits.

The selective call system under discussion is comprised of an encoder capable of generating a specific number of addresses and a group of receivers, each designed to respond to its particular address. If desired, each receiver could be set up to respond to more than one call. Thus, a group of receivers could all be alerted at one time. The model described provides 511 different addresses. The technique used, however, can provide any practical number of addresses.

In the model described, an address consists of a combination of two carriers, each of which is turned on or off as determined by a 511-bit sequence, or "word." (See Figure 1.) The same word is simultaneously generated in two shift registers, and each word controls the on-off condition of one of the carriers. Although the words are identical in structure, 511 discrete phase relationships may be obtained between them. A specific phase relationship determines an address. That is, an address is determined by the time displacement, in discrete bits, between the elements of one word used as a reference, and the corresponding elements of the other word, after the other word has been appropriately delayed, as will be described in subsequent paragraphs.

Each receiver receives the two carriers and detects the two binary sequences. Logic circuitry incorporated into the receiver operates on the reference word, regenerating it in a different

phase. If the regenerated word and delayed word are both in the same phase relative to the reference word, the receiver's call-indicating-circuitry is activated.

The system's operation depends on the unique characteristics of binary sequences known as "maximum-length, shift register sequences" in generating and recognizing the multiple addresses used. To describe the system, therefore, these binary sequences require some discussion.

Maximum-length, shift register sequences can be generated in the following fashion. If, as in Figure 2a, a series of storage elements (a through f) is loaded with a succession of binary digits, we may, as indicated, perform modulo 2 addition on the contents of two or more storage cells. If the storage elements are connected as shifting registers, we may, by the application of a shifting pulse, transfer the contents of all storage elements one unit to the left.

Simultaneously, we may introduce the result of the modulo 2 addition into the storage cell left empty, as in Figure 2b. As this process is

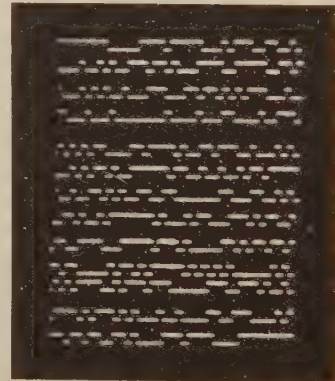


Fig. 1 - 511-bit binary sequence used in the experimental model.

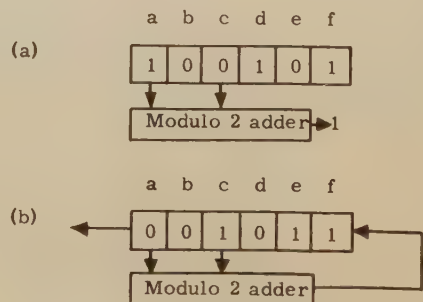


Fig. 2 - "Word" generator.

Agreement = +
Disagreement = -

(a)	1	1	1	1	0	0	0	1	0	0	1	1	0	1	0
(b)	1	1	0	1	0	1	1	1	0	0	0	1	0	0	0
	+	+	-	+	+	-	-	+	-	+	-	-	-	-	+
$\Sigma (+, -) = -1$															
(a)	1	1	1	1	0	0	0	1	0	0	1	1	0	1	0
(c)	1	0	0	1	1	0	1	0	1	1	1	1	0	0	0
	+	-	-	+	-	+	-	-	-	-	+	+	+	-	+
$\Sigma (+, -) = -1$															
(a)	1	1	1	1	0	0	0	1	0	0	1	1	0	1	0
(d)	1	1	1	1	0	0	0	1	0	0	1	1	0	1	0
	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
$\Sigma (+, -) = +15$															

Fig. 3 - Element-by-element comparison of an m-sequence with cyclic permutations of itself.

repeated, a succession of binary digits will pass through the storage element "a." It is easy to see that this sequence of binary digits, referred to as a "word," will be periodic. In fact, for any length shift register, say "n," and for certain corresponding inputs from the register to the modulo 2 adder, the resulting word may be as long as $2^n - 1$. Sequences of length $2^n - 1$ generated in this manner are called maximum-length, shift register sequences, abbreviated "m-sequences" for convenience, and have been studied by Huffman¹, Golomb², Zierler³, and others. These sequences have properties which make them very useful as elements of a selective calling code. These properties are:

(a) If an m-sequence is compared element by element with any shifted version of itself (that is, a cyclic permutation of itself) one more disagreement than agreement will result. For example, comparing (a) and (b) or (a) and (c) of Figure 3, it is seen that the eight disagreements exceed the seven agreements by one. This is true for all the cyclic displacements of the word relative to itself. Note also that the pattern of the results is a shifted version of the m-sequence.

(b) If an m-sequence is compared with an in-phase version of itself, (a) and (d), there are L agreements, where L is the number of bits in the word.

(c) If an m-sequence of length L is passed through a shift register of length $n (L = 2^n - 1)$, then any of the L possible cyclic permutations of the m-sequence can be produced by modulo 2 addition upon selected elements of the shift register. Consider as an example the m-sequence used in Figure 3 as it is shifted through a four-bit register and modulo 2 addition is performed on the contents of register elements 1 and 3, or 1, 2, and 3. Figure 4 shows the outputs obtained. These are two of the possible shifted versions of the input word.

If similar logic (modulo 2 addition) is performed on all the possible combinations of inputs to the modulo 2 adder, all 15 versions possible may be obtained; that is,

$$\sum_{r=1}^4 {}^4C_r = {}^4C_1 + {}^4C_2 + {}^4C_3 + {}^4C_4 = 4+6+4+1 = 15$$

Consider now a calling system in which the addresses transmitted are produced by the generation of an m-sequence of length L and a cyclical permutation or shift, of the same sequence. The "address" is determined by the number of shifts between the two versions of the m-sequence transmitted. For example, considering the m-sequence used in Figures 3 and 4, if we transmit simultaneously

(A) 1 1 1 1 0 0 0 1 0 0 1 1 0 1 0
and (B) 0 1 1 1 1 0 0 0 1 0 0 1 1 0 1

we can say that we have transmitted address number one where shifts to the right (B delayed relative to A) of sequence B are used as the index.

Similarly, transmitting

(A) 1 1 1 1 0 0 0 1 0 0 1 1 0 1 0
and (B) 1 0 1 0 1 1 1 1 0 0 0 1 0 0 1

corresponds to address number four under the same convention. Clearly, 15 such addresses exist, counting the zero shift as address number 15. In practice the sequence can be lengthened to suit requirements, and sequences of length $2^8 - 1 = 255$, $2^9 - 1 = 511$, or $2^{10} - 1 = 1023$, etc., can be easily generated. In the experimental model, a word length of 511 bits was used, which gives a capability of 511 addresses. Although the word length is a discrete number, the "call" transmitted is a repetition of the word, which continues as long as the call signal is turned on.

With the address capability established, a means must now be determined to transmit this.

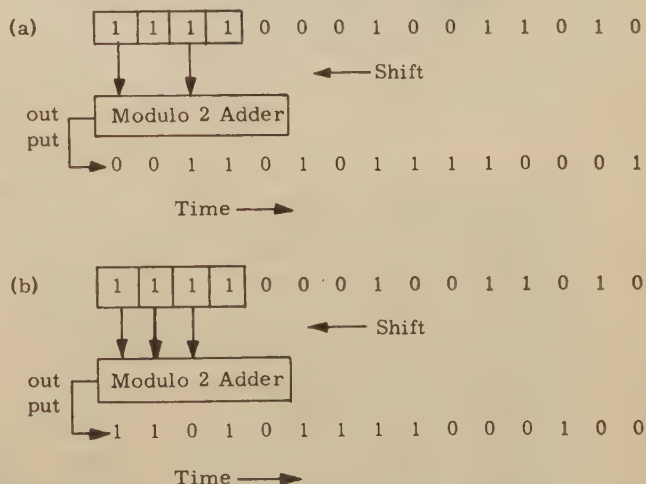


Fig. 4 - Fifteen bit, m-sequence being shifted through a four element shift register and results of modulo 2 addition of: (a) input elements 1 and 3, and (b) input elements 1, 2, and 3.

information to the various receivers in the system. This requires the transmission of the two binary functions in some form and their reconstruction in the receivers. This can be done by a variety of methods, including: (1) using the words to modulate a carrier frequency; (2) using the words to modulate two carrier frequencies; and (3) using the words to modulate one or two sub-carriers which modulate a higher carrier frequency. Method No. 2 (each word modulating a carrier) is the simplest technique from an equipment point of view. In the experimental model, however, the method used was a variation of method No. 3. Two subcarriers, each modulated by a word, were used to modulate a higher frequency carrier. The reason for this was to make the system readily adaptable to conventional communication equipments. The subcarriers used were at audio frequencies and the carrier at radio frequency.

At the receivers, the carriers must be removed and words reconstructed. There can be as many unique receivers as there are addresses possible, with each receiver containing recognition circuitry for one address. If the capability for group calls is desired, circuitry which will recognize a common call as well as circuitry for recognizing a unique call can be included in each receiver within a group.

Once the two words have been reconstructed in the receiver, the properties of m-sequence

words described previously are used to accept or reject the call. The reference sequence is sent through a shift register and modulo 2 addition is performed, which regenerates the word in a new phase. The regenerated word is compared with the incoming delayed sequence. A storage is provided which collects one positive unit for each agreement between the two delayed sequences and one negative unit for each disagreement for the sequence length, L . If the receiver receives its own address, that is, if the words are in phase, then after the m-sequence and its shifted version have passed through the receiver we will have collected L units in the storage. If, however, the two delayed words are not in phase, the call is not correct for that receiver and (by the characteristics of m-sequences) the contents of the storage will be -1 after the passage of a sequence of length L . The signal to noise ratio, S/N , between correct and incorrect calls will therefore be $S/N = (L/1)^2$. Since we are considering sequences where L can easily be 100 we have theoretically attainable S/N ratios far in excess of 40 db. In actual practice, since we do not usually need such large S/N ratios, the summations are not carried out to the full length of the sequence in order to speed signaling times.

The equipment required for a 511-address system is shown in Figures 5 and 6, which are block diagrams of the selective call encoder and decoder, respectively. The encoder has to be

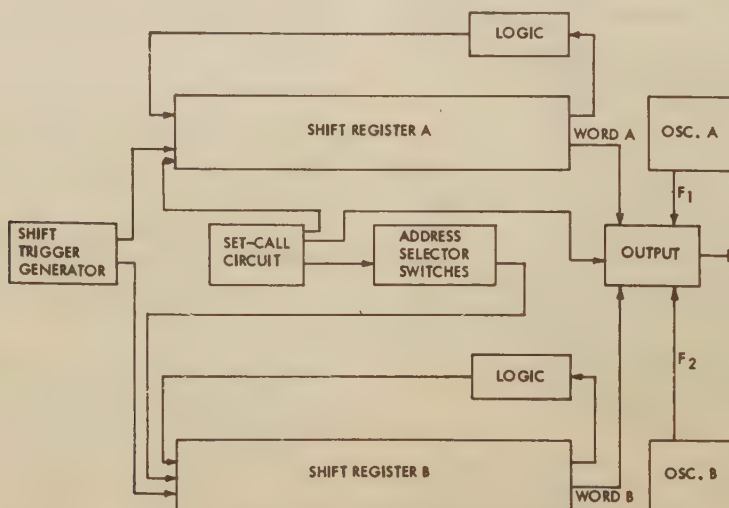


Fig. 5 - Selective call encoder -- block diagram.

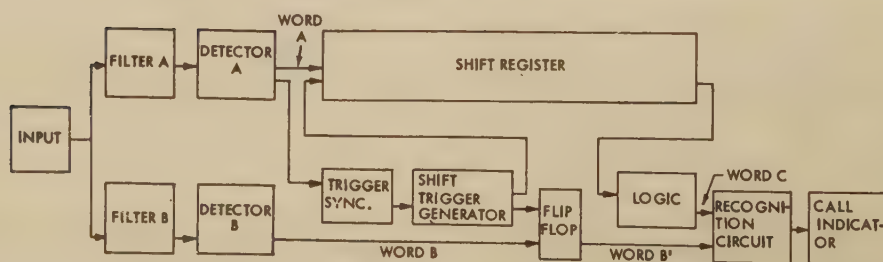


Fig. 6 - Selective call decoder -- block diagram.

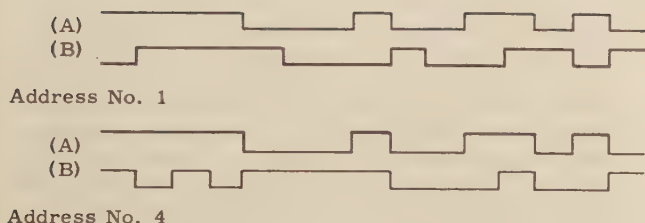


Fig. 7 - Examples of 15 bit word A; same word B delayed one bit for address No. 1 and delayed four bits for address No. 4.

capable of generating all the possible addresses. It is possible to do this with one word generator in the encoder and the capability for connecting to it any of the 511 possible logic circuits needed to get the delayed words. Less equipment is needed, however, if two identical word generators are used, with provisions for establishing their phase relationship. This method is used in the encoder of Figure 5, which operates as follows.

Shift registers A and B and their associated logic circuits generate two binary sequences (words A and B). In the 511-call system, each shift register has nine storage elements (bits), and the logic circuit performs, on two elements, an odd parity check, which is the input to the shift register. Each generated word is an m-sequence, 511 bits long. The logic circuits are the same; hence words A and B are the same. Corresponding parts of the words, however, may be displaced in time. Two examples, using an m-sequence of length fifteen, are shown in Figure 7 to illustrate the displacement.

In the 511-bit word there are 511 discrete displacements obtainable, each displacement thus determines an address. The set-call circuit and the address selector switches establish the phase relationship between the two words, A and B, generated in the encoder. Both shift registers are shifted by the same trigger generator.

Figure 8 shows 1/10 of word A and the corresponding segments of 15 of the 511 possible phases of word B. For each call, the reference word, A, (first trace) and one of the phases of word B are transmitted. As can be seen in Figure 8, each of the traces (2-16) shown is one bit delayed with reference to the previous trace and when it is used with trace 1, it constitutes one of the first 15 addresses according to our numbering system.

Oscillators A and B generate sine waves at the two carrier frequencies, F_1 and F_2 . The two carriers and the two binary sequences are fed to the output circuit, which establishes the output waveshape. Referring to Figure 9, F_1 is from oscillator A, F_2 is from oscillator B, A is a segment of the word from shift register A, and B is a segment of the word from shift register B generated during the same time. Word A determines whether carrier F_1 is sent out, and word B deter-

mines whether carrier F_2 is sent out. These four signals make up the encoder output, or call signal.

Figure 10, (a, b, and c) shows segments of words A and B and the call signal formed during a period 40 bits long. Included in this segment are nine bits shown in Figure 9.

In the model described, the carriers used are 4800 cps (F_1) and 3300 cps (F_2). The register shift rate is 400 pps.

If we define the "up" state of A as "a" and the "down" state as " $\bar{a}$ ", then it can be seen that:

word		carrier		output
$a + \bar{b}$	+	$F_1 + F_2$	=	F_1
$\bar{a} + b$	+	$F_1 + F_2$	=	F_2
$\bar{a} + \bar{b}$	+	$F_1 + F_2$	=	No carrier
$a + b$	+	$F_1 + F_2$	=	$F_1 + F_2$

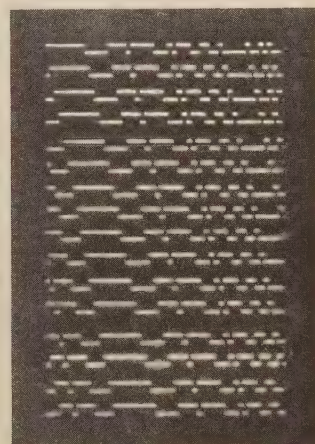


Fig. 8 - Part (1/10) of word A and 15 phases of part of word B.

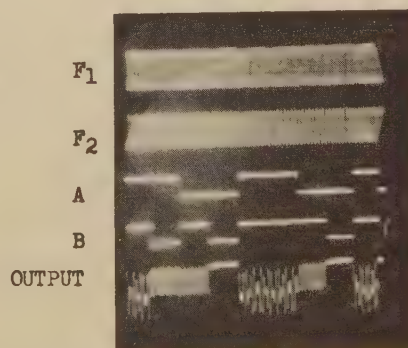


Fig. 9 - Signals in output circuit.

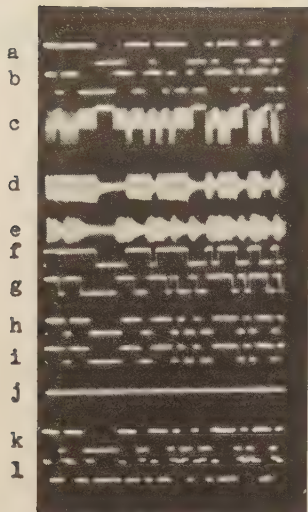


Fig. 10 - Wave shapes in encoder and decoder for 40 bit segment of the word. Word A (a); word b, displacement 97 bits (b); encoder output (c); filter B output (d); detected and shaped word A (e); detected and shaped word B (f); output of decoder logic h-7 (g); word B¹ (h); output of recognition circuit for correct call (i); word B in encoder, displacement 98 bits (k); output of recognition circuit for wrong call (l).

The audio output signal described is used as a modulating signal for an r-f transmitter. At the receiver, the r-f signal is detected and the encoder output signal becomes the decoder input signal. For operation of the decoder refer to Figures 6 and 10.

The two audio carrier frequencies are fed to filters A and B which filter off frequencies F₁ and F₂ respectively. The output of filter A, Figure 10d, consists of pulses of F₁ and is like a signal that would be sent out by the encoder if only A and F₁ were used. Similarly, the output of filter B, Figure 10e, is like that generated by F₂ and B only. These signals are passed through detectors A and B and then shaped to obtain wave forms as shown in Figures 10f and 10g. The signals are now identical in structure to the outputs of the two shift registers in the encoder. Word A is used as the input to the decoder shift register, while word B is read into a flip-flop storage stage and becomes word B¹.

The decoder shift register must operate at the same rate as the encoder shift register; hence, the shift trigger generator in the decoder is synchronized with the encoder by the trigger-synchronizing circuit, which obtains its information from the detected word A.

The logic circuit in each decoder is unique; all other circuitry is common to all receivers. The logic circuit performs modulo 2 addition on the contents of certain elements of the shift register and, as described previously, regenerates a word, C, identical to words A and B in structure but delayed with respect to the input to the shift register by a discrete number of bits. Word C is compared in the recognition circuit with the word in the flip-flop storage. If the two words, C and B¹, are in phase, the call indicator is activated. During any other phase relationship of the two words, the call indicator remains turned off.

Since detected words, A and B, may change slightly in their phase relationship (other than the discrete bit displacement transmitted) after

passing through the filters and wave shapers, (see Figure 10, f and g) word B is gated into the flip-flop at the same time that word A is gated into the shift register so that the rise and fall times of the two words will occur simultaneously. This delays the words by one bit with reference to the encoder word. As shown in Figure 10, word B¹ in the flip-flop (10i) occurs one bit later than word B at the input (10b). Similarly, word A is also delayed one bit when it is read into the shift register and becomes A¹.

The phase relationship between A and B thus remains the same as that of A¹ (1st shift register flip-flop) and B¹. For the example shown, word B is delayed 97 bits with respect to A. Similarly B¹ is delayed 97 bits with respect to A¹. To activate the call circuit, a word, C, must be generated delayed with respect to A¹ by 97 bits. This is done by using modulo 2 addition on shift register elements 4 and 7 (counting the shift register input flip-flop as element 1). Word C is shown on line h of Figure 10. Comparing lines h and i, it can be seen that they agree element by element. When the two words are compared in the recognition circuit there are L agreements per word and the result is the steady d-c level shown in line j. The d-c level attained is used to actuate the call indicator.

If word B were in any other position relative to A; for example, delayed 98 bits as shown in line k of Figure 10; then word C (4-7 logic) will be out of phase with B¹ and the output of the recognition circuit will be (by the property of m-sequences) the word in a different phase (10-1). This word, when integrated, will produce a net result of one disagreement. Consequently, it will not actuate the call circuit. Similar results will be obtained for all the calls except the correct one.

Developmental Model

The circuitry used in the laboratory model is shown in Figures 11 and 12. Transistors and semiconductor diodes were used throughout to reduce size and power consumption.

Encoder Operation

In the encoder schematic, Figure 11, there are two shift registers which contain nine flip-flop stages each. Transistors 1-18 are in register A and transistors 19-36 are in register B. The flip-flops are bi-stable and upon application of a shift pulse to shift lines A and B, the information stored will be shifted to the right. The position that each flip-flop assumes after application of a shift pulse is determined by the state of the preceding flip-flop, since this element biases the diodes connected to the bases of the following flip-flop through the two connecting resistors. Upon application of a negative shift pulse, only one of the transistors in each flip-flop will receive the trigger since only one of the diodes can pass the trigger. The diode that will pass the shift pulse is determined by the biasing applied by the preceding flip-flop.

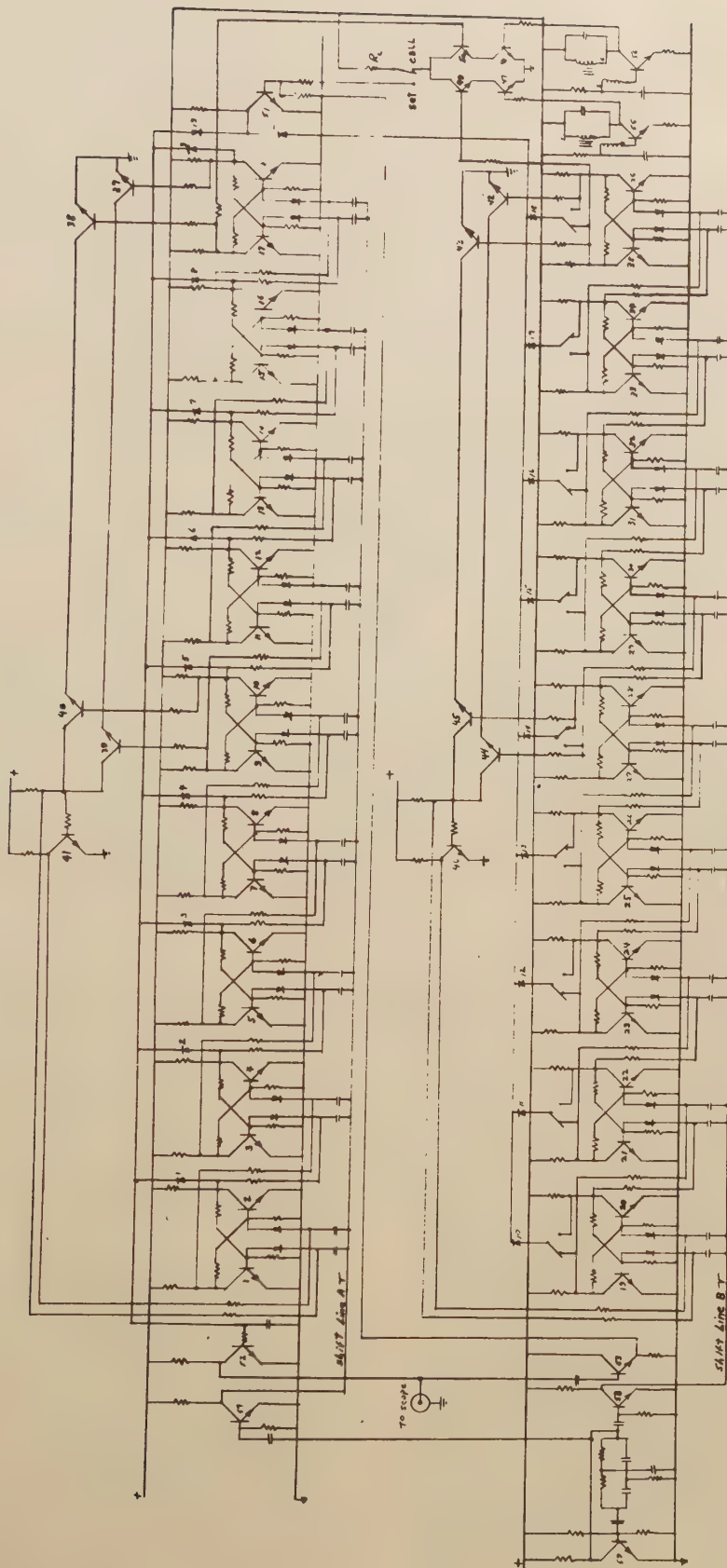


Fig. 11 - Encoder schematic.

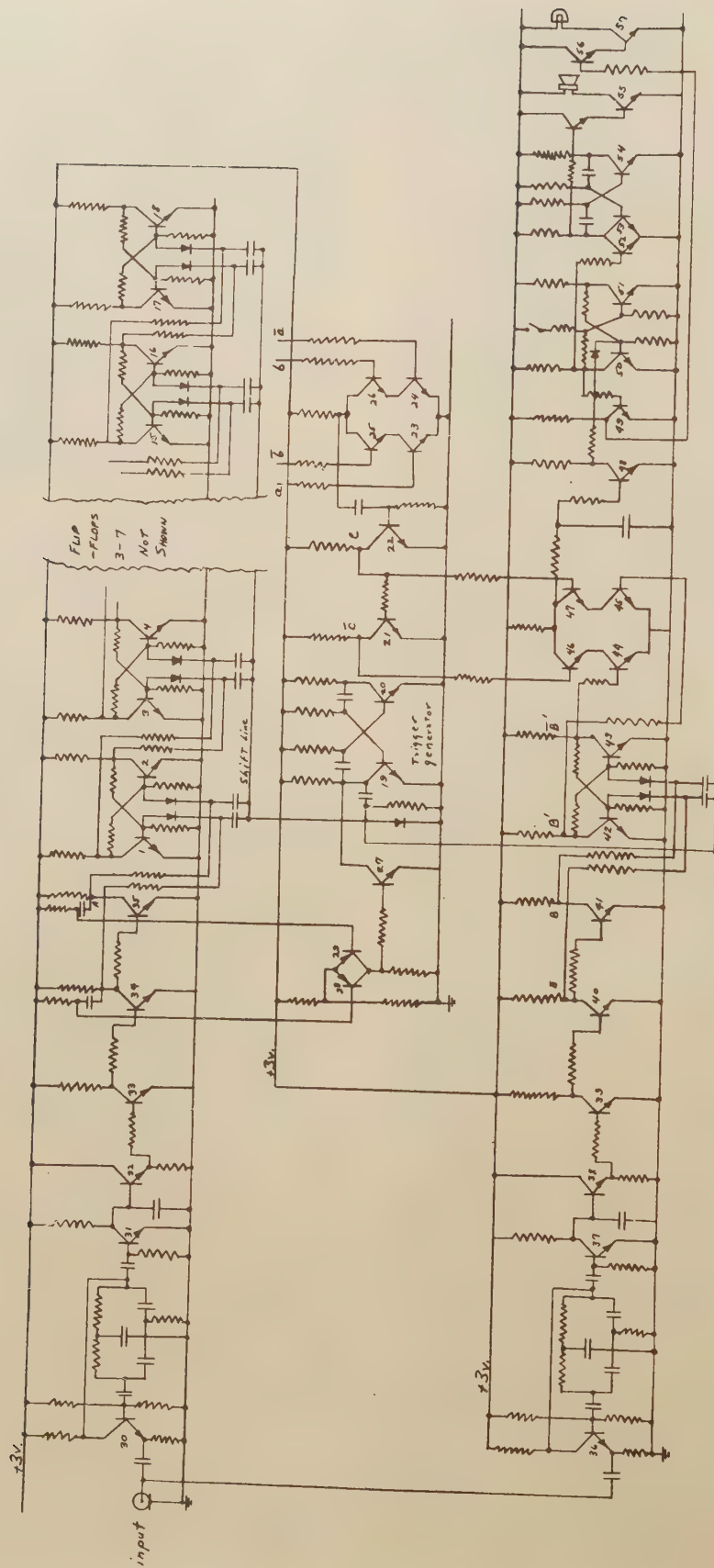


Fig. 12 - Decoder schematic.

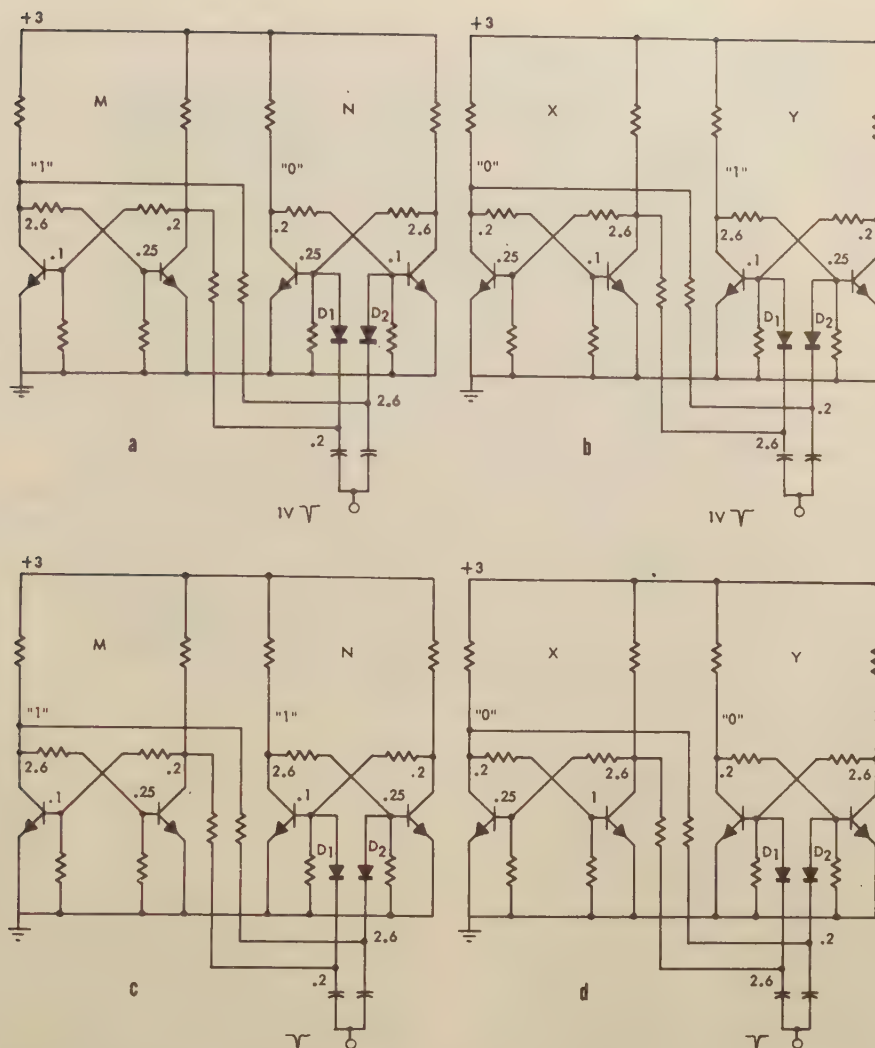


Fig. 13 - Operation of shift register: (a) elements M and N before shift trigger; (b) elements X and Y before shift trigger; (c) M and N after shift trigger; (d) X and Y after shift trigger.

An example of this operation can be seen by reference to Figure 13. If we define a "one" as the condition existing in a flip-flop when the left transistor is turned off, and a "zero" as the condition when the left transistor is turned on, the voltages shown are typical of the conditions indicated. With a "one" in M and a "zero" in N, as in Figure 13a, diode D_1 is almost turned on while diode D_2 is back-biased by 2.5 volts. Therefore, when a shift pulse of one volt appears at the input, only diode D_1 will pass it. The left transistor of N is thus turned off, which produces the condition shown in Figure 13c.

If the initial conditions are those shown in Figure 13b, diode D_2 will pass the trigger when it occurs. The results will be the conditions shown in Figure 13d. If another trigger pulse occurs when conditions are as shown in Figures 13c and 13d, then diodes D_1 and D_2 , respectively, will conduct, and tend to turn their respective transistors off. Since these transistors are

already turned off, no change in state takes place. From this it can be seen that upon application of a shift pulse, each flip-flop is set according to the state of the flip-flop to its left (as drawn). In a shift register, the flip-flop stages are connected as shown in Figure 11. Upon application of a shift pulse each flip-flop maintains its state long enough to direct the trigger to the succeeding stage, then changes as directed by the preceding stage.

Connected to each shift register is a 2-element regenerative logic circuit which contains transistors 37-40 for register A and transistors 42-45 for register B. Both circuits are the same and perform an "odd" parity check on shift register elements one and five (counting the output flip-flop as one). Transistors 41 and 46 invert the logic outputs and, in conjunction with the logic outputs, bias the trigger-directing diodes of the input elements in each register. For example, if there were a "one" in element 1 and a

"zero" in element 5, or a "one" in element 5 and a "zero" in element 1, then the collectors of transistors 39 and 40 are near ground potential and the collector of transistor 41 is near B^+ . The input flip-flop is, therefore, biased as though a flip-flop stage preceded it. With the application of a shift pulse, a "one" is read into the shift register. Similarly, if elements 1 and 5 are both "ones" or "zeros", a zero will be read into the shift register when the next shift occurs. The logic for register B is identical to that in A. Hence, both registers generate m-sequences, 511 bits long.

The shift trigger is generated by two peak-riding clipper circuits (transistors 57 and 58) whose inputs consist of a sine wave generated at 400 cps by a twin-T oscillator (transistor 59).

The correct address is set up by diodes 1-20, transistor 51, and the SPDT switches connected to shift register B. When the set-call switch is in the "set" position, transistor 51 is turned on and its collector goes to ground potential, which causes diodes 1-20 to conduct. Nine "ones" are thereby set into shift register A and the flip-flops in shift register B are set up according to the positions of the associated switches. This condition is maintained until the set-call switch is thrown to the "call" position, which allows the shift registers to operate, and closes the output circuit. The desired address is guaranteed by a re-educate circuit (transistors 52 and 53) which recognizes all "ones" in shift register A and applies a trigger to the base of transistor 51. This circuit is also a source for a trigger which occurs once per word length (every 511 bits).

The audio tones are generated by two sine wave oscillators (transistors 55 and 56). The two tones and the two words are combined in the output circuit which consists of two "and" gates with a common load, R_L . This signal is used for modulating an r-f carrier.

The complete encoder, using standard components, is contained in a case 2" x 4" x 12". This volume could easily be cut to 1/5 its present size if 1/10 watt resistors and subminiature components were used. Total power requirement of the encoder is 40 ma. at 3 vdc.

A second encoder was constructed and is a copy of the one described, except that address selection is made by a standard telephone dial which uses a three-digit call address. Dialing the address sets an equivalent binary number into a "store" and when the 3rd digit is dialed, the binary sequence is read into shift register B, and the "call" circuit is closed.

Decoder Operation

The decoder input signal is the encoder output and is applied to two, twin-T filters (transistors 30 and 36), where the two tones are separated (Figure 12). The word envelopes are obtained at the output of detectors 31 and 37 and are amplified and shaped in passing through transistors 32-34 and 38-40. Word A, inverted,

appears at the collector of transistor 34, and word B, inverted, appears at the collector of transistor 40. The words are again inverted by transistors 35 and 41 so that word A and its inverse and word B and its inverse are available for gating the inputs to the shift register and flip-flop B* (transistors 42 and 43). The shift trigger is obtained by differentiation of the output of the trigger generating flip-flop (collector 19). With no signal, the flip-flop free-runs at approximately 380 cps. When a received signal is present, word A and $\bar{A}$ are differentiated and each change in the word causes a synchronizing trigger pulse to appear at the collector of transistor 27. This trigger synchronizes the decoder shift rate to the encoder shift rate.

Each receiver, to be unique, must contain its own logic circuit for generating word C. Rather than construct a large number of receivers to prove the system, a two-element modulo 2 adder was built which could be switched to any of the 36 possible two-element inputs. Therefore, one receiver is made equivalent to 36 receivers in that it can be changed to receive any of 36 addresses. This modulo 2 adder (transistors 23-26) is similar to the logic used in the encoder and when connected to the shift register, a and $\bar{a}$ go to one of the register flip-flops, and b and $\bar{b}$ go to another flip-flop. To obtain other calls, other modulo 2 additions must be made.

The modulo 2 adder output is coupled to an amplifier to produce word C, which is subsequently inverted by transistor 21 to obtain $\bar{C}$. Word C and its inverse are applied to the recognition circuit, which consists of two "and" gates (transistors 44-47) used to compare words B^1 and C; an integrator to store the output; and a control amplifier (transistor 48) from which the indicator gets its signal. In the absence of a call, transistor 48 is turned on and its collector is close to ground potential. The integrating capacitor is charged to the level determined by the voltage dividing resistors. When words B^1 and C are in phase, there is agreement at each bit, and the collectors of transistors 46 and 47 become nearly ground potential. After a period that depends on the time constant of the integrator, transistor 48 is shut off, which activates the call signal. If words B^1 and C are not in phase, the comparator circuit output consists of the word in a different phase (as in Figure 10-1) and since the integration of this word is almost zero, transistor 48 remains turned on.

Decoder power consumption is 30 ma. at 3 vdc exclusive of the call indicator. It occupies a volume 3" x 3" x 6". Small components are used in the shift register. All other circuitry uses standard components. The call indicator circuitry of Figure 12 (transistors 49-57), can light a lamp and buzz a speaker. These signals can be set by a switch to come on only as long as the receiver is called, or, to come on when called and remain on until manually turned off.

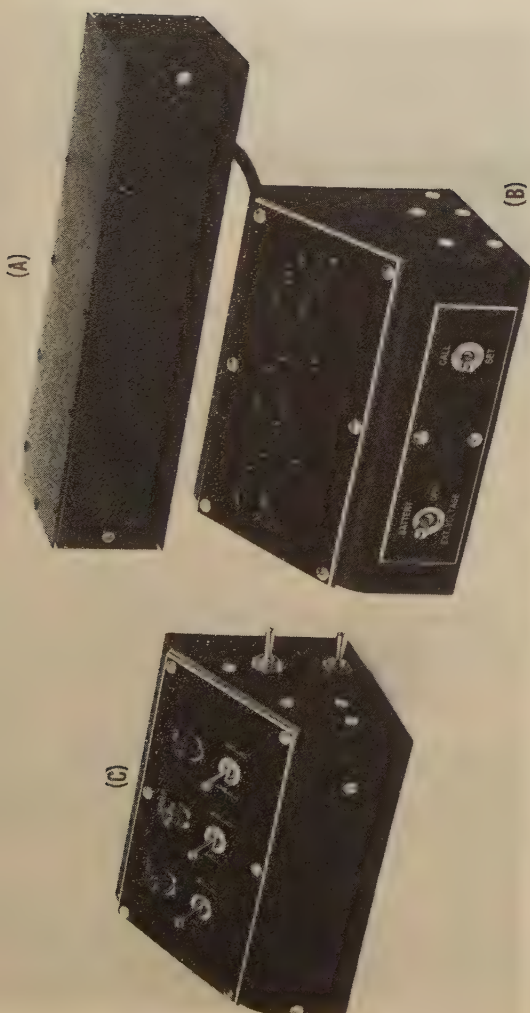


Fig. 14 - Experimental model of selective signaling system: (a) encoder; (b) switch panel, 5ll call capability; (c) decoder and indicator panel, three call capability.

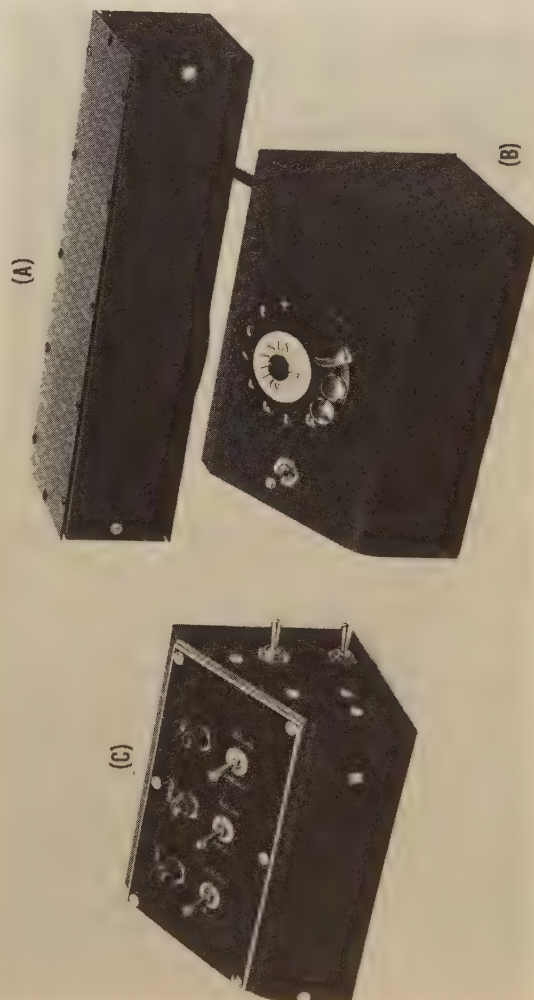


Fig. 15 - Experimental model of selective signaling system: (a) encoder; (b) phone dial, 5ll call capability; (c) decoder and indicator panel, three call capability.

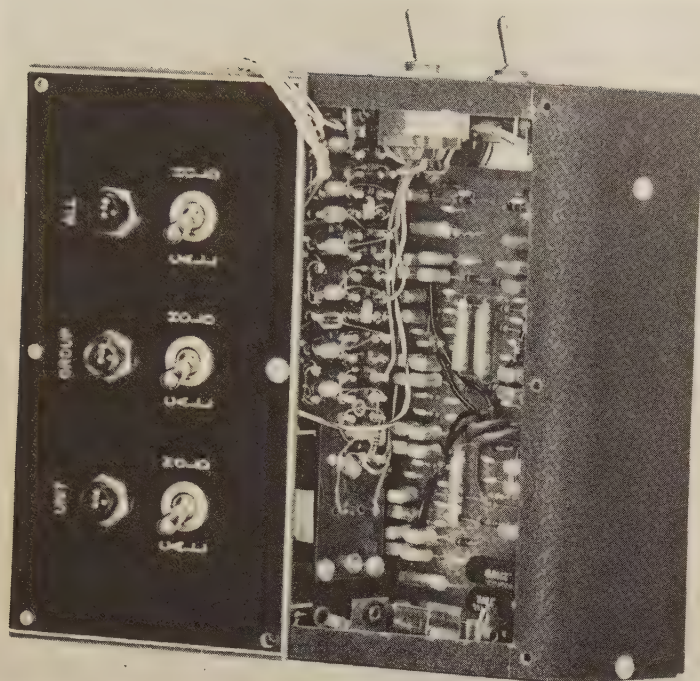
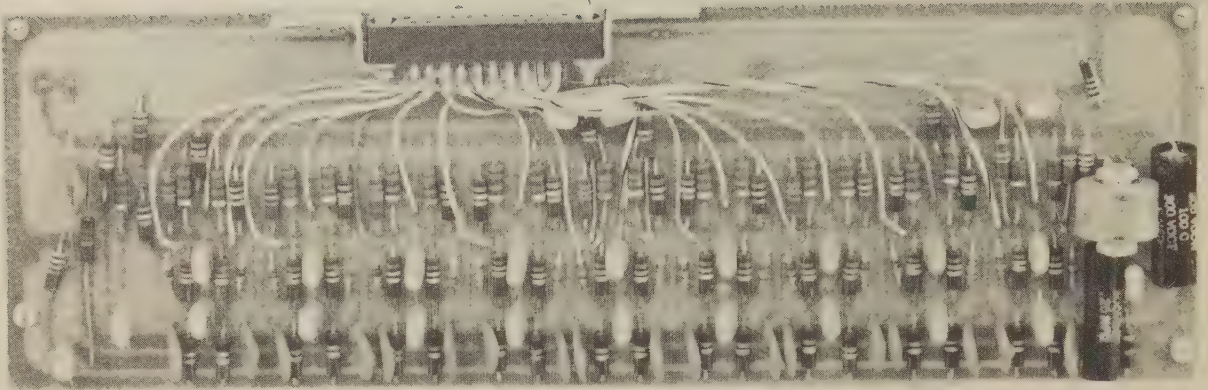


Fig. 16 - Decoder and indicator panel for three call capability.

(A)



(B)

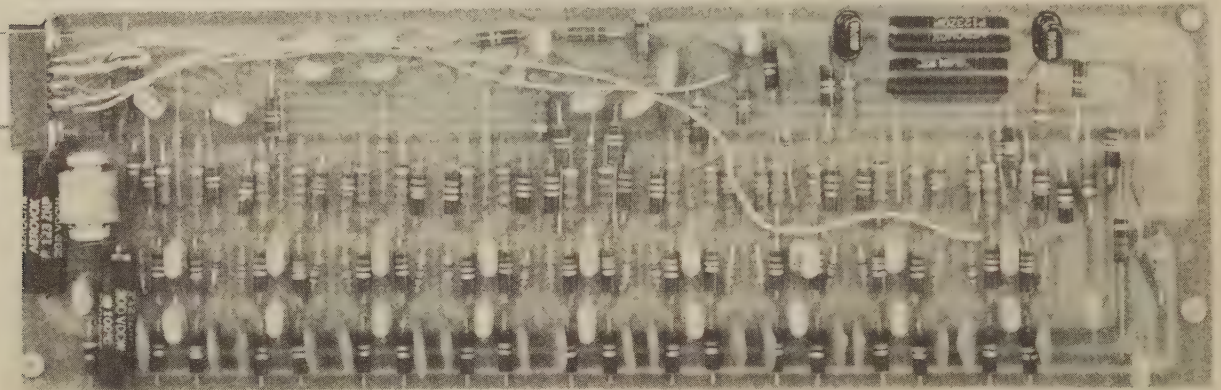


Fig. 17 - Encoder circuitry: (a) word B generator (511 bit) and tone B oscillator; (b) word A generator, tone A oscillator and trigger generator.

A second model of the decoder was built to show that multiple calls can be recognized in one decoder. The first decoder was copied and two logic circuits, two comparator circuits, and two indicator circuits were added so that the decoder could recognize a choice of three addresses. This demonstrates the capability of individual or group calls.

Figures 14 to 18 show the experimental equipment.

Summary

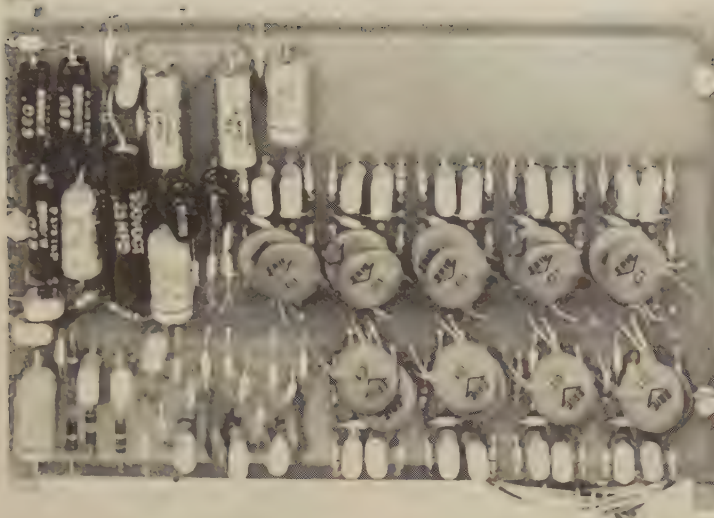
The system described permits transmission from a central location so that a particular receiver or group of receivers can be selectively called. Furthermore, with this system, controls can be operated remotely. The equipment offers many advantages over other methods. A large number of addresses is as simple to establish as a nominal number. For example, $(511)^2 = 261,121$ calls can be made using three tones and three words in the system instead of two words and two tones; or, the word could be lengthened and two tones used.

The equipment can be made small, with low power consumption, and precision components are not required. It is easily adapted to common communications systems. Protection against incorrect calls is excellent. Furthermore, should the carrier signal fade, no call would be received; but other nearby receivers would not respond to the call, which eliminates "wrong numbers."

References

1. D. A. Huffman, "The Synthesis of Linear Sequential Coding Networks," Proceedings of the Third London Symposium on Information Theory, September 13, 1955.
2. S. W. Golomb, "Sequences with Randomness Properties," The Glen L. Martin Co., Terminal Progress Report under Contract Req. No. 639498 Account No. 7570-505-739, Purchase Order SC-54-36611, June 14, 1955.
3. N. Zierler, "Linear Recursive Sequences I," Group 34, Lincoln Laboratory, Massachusetts Institute of Technology, December 2, 1957.

(A)



(B)



Fig. 18 - Decoder circuitry, experimental model: (a) word A detector and shift register; (b) word B detector and three, two element logic and comparator circuits.

NEW RUGGEDIZED HAND HELD MICROPHONE FOR MOBILE RADIO EQUIPMENT

A. Brouns, G. Salisbury, and R. Troxel
Shure Brothers, Incorporated
Evanston, Illinois

SUMMARY

The increased use of mobile radio equipment has resulted in an emphasis on intelligibility, reliability and a decrease in cost and weight.

The use of the controlled magnetic cartridge in place of carbon has done a very effective job of increasing intelligibility.

The use of plastic in the case of a hand held microphone has resulted in a reduction in both cost and weight. Using some of the new high impact plastics, the case demonstrates physical characteristics that exceed those of metal on almost every point. This plus other modifications in the mechanical and electrical design of the unit gives a microphone that is more reliable at extremes in operational environmental conditions that are incurred in mobile use.

Introduction

A recent article in LIFE magazine pointed out that the success or failure of Road Building Contractors hinged on the most efficient use of heavy duty earth-moving equipment. Profits from their operations were often tied to a few cents per cubic yard of material moved at the right time and place. To gain greater operational efficiency their equipment is being directed by mobile radio phone both on the move and at work.

Better communications are deemed absolutely necessary to attain better efficiency and ease of operation in a great many industries. Mobile radio phone is the logical answer to some of these demands.

With this increased usage the requirements for reliability, intelligibility, and lower cost are becoming more stringent.

Solutions

It is the purpose here to discuss what has been done in designing the "Ten-Four" microphone to meet these requirements.

The increased intelligibility is necessary to overcome ambient noise handicaps, radio interference and to make the data transmission fit into ever smaller frequency band widths.

The use of magnetic and dynamic cartridges has given increased intelligibility.

H. A. Johnson and Leo Rosenman in their paper presented to this conference in December of

1957 discussed in some detail the advantages of using dynamic and magnetic cartridges to improve intelligibility.

The need for greater reliability is self-evident and is being met by design changes, some subtle and some drastic.

The need for lower cost is also self-evident. However, methods for reducing costs are not.

The components of the hand held microphone are already at the minimum to carry out its assigned function. The means of reducing the cost are thus narrowed down to reducing the cost of the components without sacrificing durability and reliability.

Since the radio phone provides a vital communication link, it would be well if all the new equipment could be tested and evaluated under actual operating conditions before being put into large scale use. Demand and competition make this impossible, so the best alternative is to simulate these conditions in accelerated tests.

The major innovation in the design of the "Ten Four" microphone was in the use of the high impact "Armo-Dur" for the case. The case itself was designed to be used with components which have a good service history for reliability and durability.

Innovation Tested

The use of high impact "Armo-Dur" plastic in place of the traditional metal for a part which



Fig. 1 - "Ten-Four" hand held microphone.

must be durable is an innovation that was given thorough testing.

The tests were set up to determine the results of use under normal and abnormal conditions. All normal stress conditions must be included in any test program. However, abnormal stress conditions must be considered on the probability of their happening and the effect.

Vibration is one of the most prevalent mechanical stress conditions and is the one given the greatest amount of attention in testing the new "Armo-Dur" case.

Fig. 2. shows the microphone mounted in place on an American Tool Company shake table. The microphone is mounted on a bracket which oscillates at about 18 cycles per second and moves through the path as shown in Fig. 3.

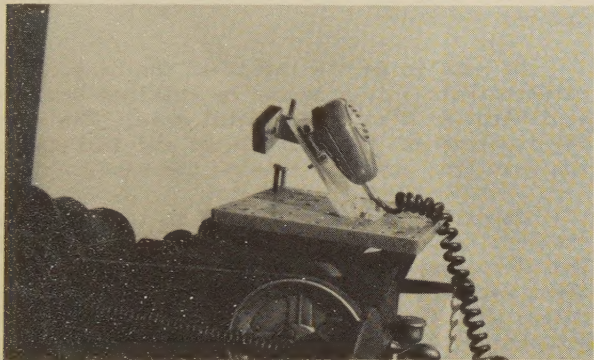


Fig. 2 - Microphone mounted on shake table.

The maximum acceleration experienced was about 12 gs. and the test was continued for 8 hours.

Fig. 4. shows the microphone on a bracket that is attached to the lower spring saddle on the front axle of a car where it rode for some 20 hours over all kinds of roads from the turn-pikes to very rough gravel roads. Neither this test nor the one mentioned earlier resulted in any effect on the hang-up button, the functioning of the microphone, or the response.

It should be noted here that we do not expect anyone to mount a microphone on the front axle of a car. It is merely an attempt to subject the microphone to mechanical stress conditions which are more severe than those expected in usage.

Anyone having watched the gyrations of a microphone hung on a motorcycle handle bar will have to agree that vibrations can be quite severe.

Since the microphone is hand held, it may be dropped. The "Ten Four" microphone was dropped 10 times from a six foot height onto a concrete floor with no adverse effect on the response, or mechanical functioning and only slight marring of the finish.

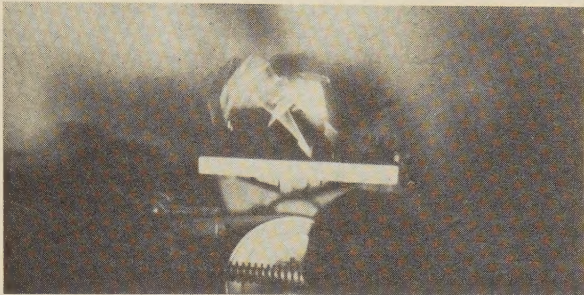


Fig. 3 - Motion path microphone during shake test.

The high impact plastic has the inherent ability to go through greater elastic deformation than its metal counterpart. Impacts that permanently deform the metal case only mar the high impact plastic.

Being dragged by the cable over the street is only one of the hazards a hand held microphone is subjected to when being used with motorcycles or other open vehicles. To simulate this, the "Ten-Four" microphone was dragged by the cable behind a car at speeds up to 30 miles per hour. The response or functioning of the "Ten-Four" was not affected after having been dragged more than 3 miles. The case was marred but it was still good and tight.

The metal cased microphone tested at the same time did not fare as well. The case deformed under the repeated poundings until the screws holding the case halves together came out. The cartridge was still in good operating condition even though it had been disconnected from the cable and case. It would have been very nearly impossible to repair the case.

To simulate high temperatures such as those found inside of closed cars setting in the sun, the "Ten-Four" was exposed to 165°F. continuously for 2½ months.

A pair of "Ten-Four" microphones were also placed in a car where they were exposed to dust, dirt, vibration and to the elevated temperatures

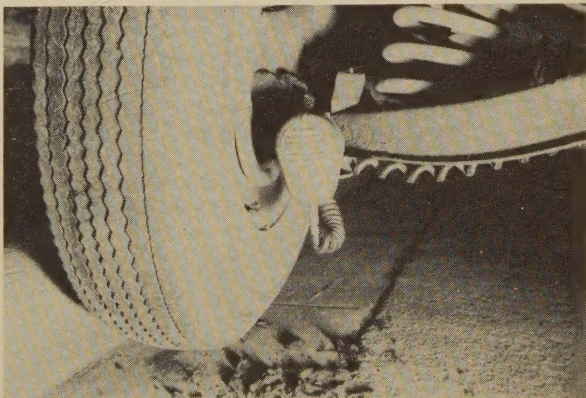


Fig. 4 - Microphone mounted on car axle.

that are normal for a closed car setting in the sun. The highest air temperature recorded was 138 degrees Fahrenheit. The total effect of these tests was a discoloration of the cable and a slight opening of the case at the parting surfaces.

Two of the microphones were tied to a duct which is the exhaust for the plating room scavenging system. Here the microphones were exposed to a corrosive atmosphere as well as the elements of weather and sunshine.

There was no effect on the microphones at the end of three months, although the fumes from the plating room so deteriorated the duct that it had to be replaced.

It would make this paper unnecessarily long to describe all of the tests such as drop, shipping, high humidity, etc., to which the microphone was subjected. This is also true for the tests such as continuous operation to which the switch and transistorized preamp were submitted. The results of these tests indicate that there was no effect or that the microphone would continue to operate far longer than any design standard that has been set to date.

Designed For Operator

A piece of communications equipment is no better than the person who operates it. Thus any piece of equipment should be designed to help keep the operator comfortable and more efficient.

This was kept in mind during the designing of the "Ten-Four" microphone. The size and shape of the case makes it easy to hold and operate in either hand. A smaller coiled cord was chosen since it required less force to extend it and less fatigue for the operator.

It is also here that the extra benefits of the "Armo Dur" case began to show up.

The thermo conductivity for the high impact "Armo Dur" is about 3% of that of a metal case. This gives the microphone a feeling of being warm to the touch and more comfortable to hold.

The lighter weight of the high impact "Armo Dur" helps make the whole microphone weigh less than its metal cased predecessor.

The lighter weight facilitates handling and makes it easier to mount. It also helps reduce marring of the case finish when the microphone is dropped or swung against something.

Now it is inevitable that the surface of the case is going to wear and be marred by the hand-

ling, dropping, and banging that it is subjected to in everyday use.

If the case were metal, this would mean at least touch-up painting or maybe even replacement of case parts.

With the "Armo Dur" case however, wear from handling will not affect appearance since the color is uniform through the walls of the case. Marring of the case can easily be removed by buffing.

"Armo Dur" is a nonconductor. This is both an asset and a liability. Being a nonconductor it eliminates shock hazard caused by improperly grounded or faulty equipment and the annoying static discharges so often experienced when a metal object is touched.

A nonconductor does not offer any appreciable electrostatic shielding which is very necessary with the high impedance magnetic and dynamic cartridges.

By metalizing the inside of the case, electrostatic shielding can be obtained that is equivalent to that of the metal case. The shielding is permanent being insulated and isolated by the case from anything outside the case.

In all the tests conducted on the microphone the results were interpreted from the effect on the microphone as a whole. The results of the tests were not considered as being satisfactory unless all of the components of the microphone had passed them.

The evaluation of all the mechanical and environmental life tests conducted proves that the "Ten-Four" microphone is rugged enough to continue to function under the most exacting operational conditions.

Conclusion

The use of the mobile radio phone is becoming more wide spread with the recognition of its advantages. As is usual with increasing use comes the demand for better equipment at a lower cost.

As an answer to this demand, the "Ten-Four" hand held microphone was designed using internal components with proven reliability and high impact "Armo Dur" case.

The completed product is a microphone that is lighter in weight, lower in cost and the results of exacting environmental and mechanical tests show that it is more than sufficiently rugged.

